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The Application Of Continuous Forces To Orthodontics

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Introduction

Increasing evidence suggests the desirability of employing orthodontic appliances which are capable of delivering light continuous force. [1 2 3] An analytic approach involving physical and engineering principles rather than a trial and error procedure should guide the development of orthodontic appliances of this type and point the way for orderly clinical and nonclinical research. Accordingly, it is the function of this paper to consider the basic biomechanical principles involved in the production of light continuous force.

Force in orthodontics is useful only insofar as it initiates a desirable tissue response. [4 5 6] It seems reasonable to assume that this response is a function of the pressure distribution in the periodontal membrane when a force is applied to the coronal portion of the tooth. Therefore, statements concerning total force application must be tempered by the realization that this force is distributed throughout the membrane in a manner which depends upon the root (length, diameter and contour), the nature of the periodontal membrane and the site of force application. [7]

In order to define precisely the force system employed for tooth movement, certain characteristics must be considered: 1) the magnitude of the force, 2) the direction of the force, 3) the point of application of the force, 4) the distance over which the force acts and 5) the uniformity of the force within this distance.

Even though theoretically it would be possible to produce any type of tooth movement with a single force or two equal and opposite forces, the realities of treatment require a more complicated distribution of forces. For instance, a single force acting through the center of resistance of the root could move a tooth bodily. However, the impracticality of such an application for pure translation necessitates the placing of three forces (a single force and two equal and opposite forces) on the crown of the tooth. No matter how complicated the force distribution on a tooth may be, its specifications may be given quantitatively. Since it has been traditional in orthodontics to measure distance by units of the metric system (millimeters and centimeters), it is desirable for reasons of consistency to measure force in grams and moments in gram-millimeters.

The forces used in orthodontic appliances have their origin primarily in elastically deformed wires which absorb and release energy during loading and unloading. Since orthodontists are concerned with the elastic or "spring" properties of wire, it is desirable to refer to such mechanisms simply as orthodontic springs. Orthodontic springs may take advantage of either the bending or torsional properties of a wire. A finger spring and a vertical loop are examples of force derived from bend-

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ing a wire. On the other hand, in a coiled extension or compression spring or a third order bend (torque) in an edgewise archwire, the force is obtained from the twisting or torsional properties of the wire.

In order to design and utilize springs for orthodontic appliances, three spring characteristics must be considered. They are: 1) the relationship between force and deflection, 2) the load at which permanent deformation occurs and 3) the range of activation within the elastic limit.

The relationship of applied force to wire deflection is defined by Hooke's law which states that within the proportional limit of any material deflection is proportional to load. Hence, throughout the range of activation of a spring, the quotient of applied force divided by deflection is a constant. This constant is termed the *spring constant, spring gradient* or the *load-deflection rate* and is given in grams per millimeter or gram-millimeters per radian. It represents the load necessary to produce a unit deflection.

Load-deflection rates vary considerably in commonly-used orthodontic appliances. Rate variation can be demonstrated by comparing two 10 mm stainless steel vertical loops (Figure 1). The respective rates of loop A (.016 wire) and loop B (.021 x .025 wire) are 60 gm/mm and 310 gm/mm. Loop B requires 310 gms for every millimeter of deflection and conversely, during unloading, a drop of 310 gms occurs with each millimeter of tooth movement. Loop A during unloading has a reduction of only 60 gms for every millimeter of tooth displacement. Springs that have lower load-deflection rates deliver more constant forces during unloading, since there is less force change from one millimeter of activation to the next. Therefore, loop A provides the more constant force of the two and is demonstrated graphically by the flatter slope of the plotted line.

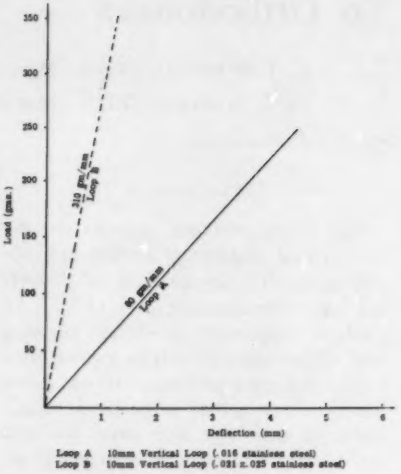

Fig. 1 Load-deflection rate graph. Loop A which has the lower load-deflection rate delivers a more constant force than loop B.

In some applications the load-deflection-rate may vary in a given spring, particularly if large deflections are employed. This is not a contradiction of Hooke's law, but reflects the changes in spring configuration that occur during loading. Since these springs lack a linear relationship of load and deflection, an average rate may be used to describe the force gradient. For greater accuracy, however, a table or graph showing the force for every millimeter of activation is preferable to predicting the force on the basis of an average spring constant.

If successive loads are placed on a spring, a point is reached at which permanent deformation will occur. The greatest load that can be applied safely to a wire without permanent deformation is the *allowable working load* or the *maximum load* and it is determined usually by both theoretical calculations and experimental data. The largest

force placed on a member during a given activation is the *final load*. In order to minimize accidental permanent deformation in springs, it is desirable to apply a final load that is considerably less than the allowable working load.

Closely related to the allowable working load is the *range of activation* for static loading. The range of activation is the greatest distance through which a flexible member can be deflected without permanent deformation. Springs that possess high allowable working loads and low load-deflection rates have high ranges of activation.

The desirability of continuous forces in orthodontics may be questioned if high load-deflection rates are employed. A high gradient spring acting continuously between appointments will demonstrate a marked lack of uniformity in force magnitude. For this reason, appliances of this type must be activated so that the final load is great enough to insure an average force level which is adequate for tooth movement. Physiologically, the final load is apt to be too large and hence, undesirable changes in the periodontium may follow.

The ideal orthodontic spring would have the ability to release a constant force throughout the entire range of its activation. This is not to imply that force levels should remain constant during a given type of tooth movement, but rather that sudden changes in force magnitude should be eliminated. Since Hooke's law suggests that no spring is completely constant in its action, the quest for a constant force spring resolves itself into the utilization of springs with low load-deflection rates. In these terms a constant force spring is one that approaches a zero rate. With a low gradient it is necessary, however, to assure a sufficiently high allowable load to prevent permanent deformation before reaching the desired final load. It can be seen that the design of relatively constant force springs requires the development of flexible members that have both low rates and high allowable working loads. Mechanisms of this type are characterized by long ranges of activation and the ability to absorb considerable energy.

It is the purpose of this paper to consider the various factors that are important in the design of low-gradient springs and to present both theoretical and experimental documentation of the principles involved. Although the bending properties of wire are primarily given to illustrate spring design, many of the concepts, at least in part, may be applied to other flexible members used in clinical orthodontics.

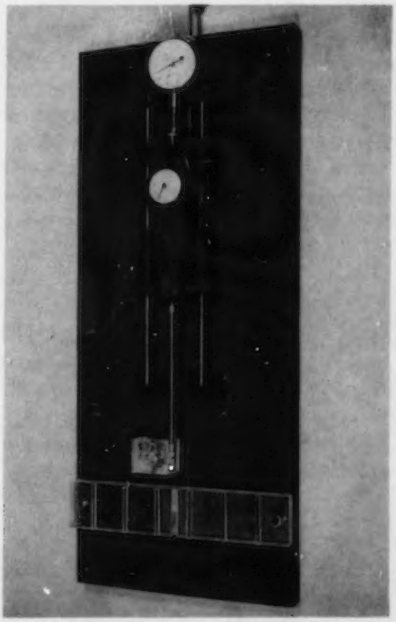

Fig. 2 Hunter Gauge with dial indicator to record load and deflection simultaneously.

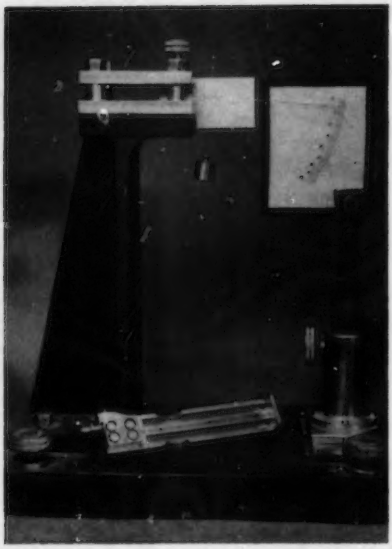

Fig. 3 The Franke Static Flexor Tester.

Load deflection characteristics were experimentally determined by a specially built instrument incorporating a Hunter mechanical force gauge, L-500, and a Brown and Sharp dial indicator (Fig. 2) and the Franke Static Flexor Tester (Fig. 3). All springs were formed from orthodontic wire, (18-8 stainless steel), purchased on the open market and following fabrication, unless otherwise specified, were stress relieved at 850° F for three minutes. Experimental data should be considered only representative since significant variation was noted in different batches of wire even from the same processor.

Factors Influencing Spring Design

Mechanical Properties: The mechanical nature of the wire used in an orthodontic appliance may alter both the rate and allowable load of a given spring.

The rate of a spring is directly proportional to the modulus of elasticity (E)*. The modulus represents a stress-strain ratio in tension or compression which expresses a measure of the stiffness of a material. It is basically a constant for most wires and is not appreciably altered by work hardening or heat treatment. Residual stresses, however, induced during cold working modify the stress-strain relationship to a non-linear form and may be responsible for a slight reduction in spring rate. Following stress relief, below the critical temperature, the gradient is raised. Disregarding residual stresses and preferential orientation, the modulus of elasticity for most practical applications can be considered a constant.

If spring configuration and dimensions remain unchanged, rate may be altered only by using various alloys with different moduli of elasticity. For instance, a steel and a gold spring identical in every respect would have rates that vary as the ratio of their moduli (Table I). Because of its higher modulus of elasticity, the steel spring would deliver 1.8 times as much force for each millimeter of activation. Accordingly, springs of a similar rate can be designed by utilizing smaller wire diameters in steel than in gold.

The mechanical property of an alloy that determines allowable working load

* $\frac{P}{\Delta} = KEI$

Where P is the load
Δ is the deflection
K is a constant for a given structure
E is the modulus of elasticity
I is the moment of inertia

Table I

Comparison of Mechanical Properties of Typical Gold and Steel Wires

	Modulus of Elasticity (psi)	Proportional Limit (psi)
Gold	16,000,000	130,000
Steel	28,000,000	260,000

Table II

Effect of Stress-Relieving Cold Worked 18-8 Steel Wires

Size	Condition	Proportional Limit (psi)
1⅛" Diameter	As cold drawn	33,000
	After stress-relief (750 - 800 F. - 1 hr.)	42,500
0.188" Diameter	As cold drawn	64,000
	After stress-relief (750 - 800 F. - 1 hr.)	96,500
0.080" Diameter	As cold drawn	157,000
	After stress-relief (750 - 800 F. - 1 hr.)	187,000

is the proportional limit (Sp)*. The higher the proportional limit the greater is the allowable working load. Unlike modulus of elasticity, proportional limit can be affected markedly by grain size, cold working and heat treatment. Cold working increases the elastic properties of a wire and, since a small diameter wire usually is subjected to greater cold working, it will tend to have a higher proportional limit than a larger wire. Removal of induced stresses produced during drawing will further enhance the proportional limit (Table II). It should not be inferred that all residual stresses are undesirable for in many instances, if these stresses are properly oriented, they may increase the apparent proportional limit.

A comparison of gold and steel springs of identical diameter (Table I) demonstrates that the allowable load of a steel wire is approximately two times as great as the gold. This comparison applies only in a high quality steel wire of small gauge where proportional limits are high. A more meaningful comparison is between gold and steel springs of similar rates and thereby different diameters. In this case, the allowable load of the steel member is 1.3 times as great as the gold.

* $M = \frac{S \text{ max. } I}{C}$ Where M is the bending moment
S max. is the maximum stress in cross section. (S max. should not exceed Sp)

$\frac{I}{C}$ is the section modulus

Confusion sometimes exists in relating resistance to permanent deformation and the rate of a spring. On the basis of "feel", a clinician may believe that a spring made of soft steel wire has a lower spring rate than an identical spring fabricated of hard steel. It should be remembered that modulus of elasticity is virtually a constant for a given alloy and therefore, the rates of identical soft and hard steel wire springs are nearly the same. The difference in "feel" can be explained by the higher proportional limit of the hard wire which requires a greater total force to produce permanent deformation.

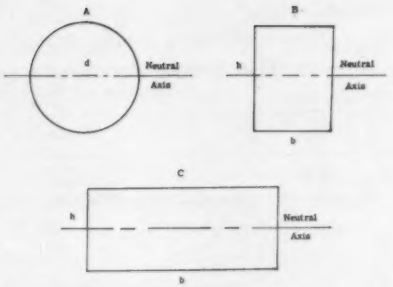

Fig. 4 Wire cross sections. A — Round, B and C — Rectangular. Neutral axis — dotted lines. d — diameter; h — depth; b — breadth.

In terms of design, the mechanical properties of a wire offer only limited potentialities. The maintenance of a given allowable load and a reduction in rate require an increase in the ratio of proportional limit to modulus of elasticity. At the present it is not possible to suggest any alloys that are significantly superior to stainless steel or gold in respect to this ratio. Perhaps, in the future new and superior alloys may be developed that can be applied to orthodontic springs.

Cross-sectional geometry: The change in rate which occurs as a result of altering the cross section of a spring wire is not simply proportional to the change in wire dimension or to the cross-sectional area. The resistance of a wire to bending and hence, its rate, is determined rather by the distribution of material around the neutral axis* (Figure 4).

It can be demonstrated that a relatively small increase or decrease in the cross section of a wire may result in a marked increase or decrease in the load-deflection rate of an orthodontic spring. Specifically, for round wire the spring constant increases as the fourth power of the diameter of the cross section. For instance, if an .010 and an .020 wire are deflected the same distance, the .020 wire exerts sixteen times as much force as the .010 wire although the diameter of the .020 wire is only twice as great. For square or rectangular wire the spring rate is only directly proportional to the width (b) of the cross section but increases as the cube of the depth (h). Thus, a change in depth has a much more pronounced effect on the amount of force required for a given deflection than does a change in the width of the cross section. For instance, the result of decreasing the wire depth by half is to reduce the spring rate by a factor of eight but, if the width is decreased by the same amount, the rate is reduced only by a factor or two. Similarly, it can be demonstrated that second order (occlusogingival) deflections in .021 x .025 wire require more than one and a half times the force needed for the same deflection in .018 x .025 wire.

One might gain the impression that a low rate spring could be designed simply by reducing the dimensions of the wire cross section. Unfortunately, this approach is limited by the fact that the allowable load changes as the third

* The neutral axis is a line passing through or near the centroid of a cross section. It represents fibers that are subjected neither to tensile nor compressive stresses.

power of the diameter in round wire and as the breadth times the second power of the depth in rectangular wire. If the dimensions of the cross section are reduced too radically, the concomitant decrease in maximum load may result in permanent deformations of a spring during its normal use. For example, an .020 wire can withstand elastically approximately eight times as much loading as can an .010 wire similarly fashioned of the same alloy. Likewise an .010 x .020 rectangular wire elastically can withstand only one eighth the load supported by an .020 x .020 wire.

The optimal cross-sectional shape is determined by the loading conditions to which a spring is subjected. If a wire is to be bent in many directions during normal use, a round cross section is the most desirable. On the other hand, the most advantageous cross section for unidirectional bending is flat wire and it can be demonstrated that the flatter the wire the more desirable will be its spring properties. If two similar flexible members, except for cross section, can support identical maximum loads, it is found that their rates vary as their diameters (round wires) or breadths and depths (rectangular wires). More precisely, the rates vary as the distance from the neutral axis to the most remote fiber in the plane of bending (c). As a specific example, a spring fabricated from .023 round wire and an .008 x .020 wire may be compared since the maximum loads for both springs are identical. By calculation the .023 round wire spring has a rate almost three times as great as the flat wire spring.

Hence, spring properties are optimally enhanced if a wire of rectangular cross section with minimal depth and greater width is utilized. Excessive cold working during the manufacture of flat wire may produce brittleness and for that reason it is a limiting factor in the reduction of wire depth.

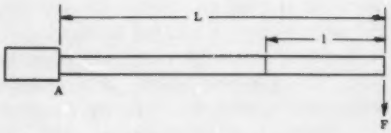

Fig. 5 Cantilever. A — point of support; L — total length of cantilever perpendicular to direction of load; l — perpendicular distance from applied force to any cross section along length L; F — applied force.

Wire configuration: The modification of the linear configuration of a wire offers the greatest potential in altering the rate and allowable working load of a spring. Since the possibilities of design are numerous, a simple and representative structure, the cantilever, has been chosen for illustration. A cantilever or finger spring is a flexible member that is restrained at one end and is completely free to move at the other. (Figure 5) To simplify the discussion it is assumed that the load is always applied at a right angle to the long axis of the wire throughout the range of activation.

A change in the length of a cantilever produces a more dramatic effect on rate than on allowable load. Specifically, the rate varies inversely as the cube of the length, but the allowable load varies inversely as the first power of the length. The influence of wire length can be illustrated by comparing a 10 mm and a 20 mm cantilever fabricated of the same kind of wire. In respect to rate, the 10 mm spring has a gradient eight times as great as the 20 mm one. Yet the allowable load is only twice as high for the 10 mm cantilever.

Modification of a cantilever along its length by the placement of coils or loops reduces spring rate without affecting allowable load. Although bends may be placed anywhere along the length of the wire, the optimum position for the incorporation of additional wire is where the bending mo-

ment is maximum. Since the bending moment is directly related to the degree of bending at any given cross section of wire, the greatest elastic deformation will occur where the bending moment is greatest. It is at this point that additional wire most effectively reduces the load-deflection rate. The maximal bending moment of a cantilever loaded with a single transverse force is at its fixed end which is most remote from the point of force application. The incorporation of a helix in the area of maximum bending decreases the spring rate without significantly altering the ability of the spring to withstand permanent deformation. The load-deflection rate in a cantilever modified with a helix is determined by the diameter of the helix, number of turns in the helix and the length of the cantilever.* For example, if a 10 mm cantilever is compared to a cantilever with one turn in a three millimeter helix, it is found that the rate of the modified cantilever is reduced about one half (forty-six per cent.) On the other hand if two turns are placed in an identical spring, the rate diminished by fifty-eight per cent.

The ability of a properly placed coil to alter the deflection properties of a spring is shown graphically in Figure 6. A three mm helix consisting of two turns has been placed at the point of restraint of an 11 mm and 26 mm cantilever (.021 x .025 stainless steel wire). As a result of placing the coil in the 11 mm cantilever the rate has diminished from 278 gms/mm to 85 gms/mm. Similarly, the rate of the 26 mm structure diminished from 25 gms/mm to

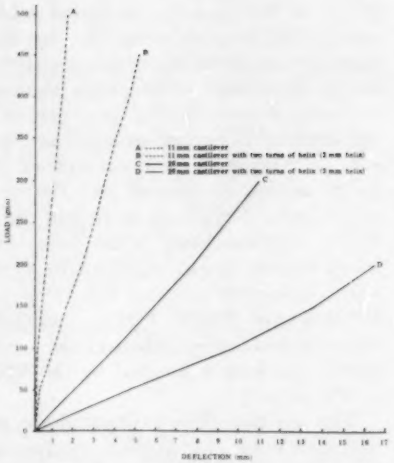

Fig. 6 Comparative load-deflection rates of simple and modified cantilevers.

11 gms/mm. The lack of complete linearity in the graph is explained by the fact that the beams were loaded with weights and therefore, the force was not always directed at right angles to the axis of the wire. For that reason an increase in rate occurs with large deflections and is most noticeable in cantilever D. It can be seen that with the use of a coil near the point of support the shorter cantilever has a more significant reduction in the spring gradient.

The elimination of sharp bends enhances the elastic properties of a spring. If a bend is acute, stress will be increased at this point and permanent deformation is more likely to result when the wire is loaded. This danger is the

$$\frac{*P}{\Delta} = \frac{EI}{2r \prod n\left(L^2 + \frac{r^2}{2}\right) + 4Lr^2 + \frac{L^3}{3}}$$

Where E = modulus of elasticity
I = moment of inertia
n = number of turns in helix
L = length of arm
r = radius of helix
$\frac{P}{\Delta}$ = load-deflection rate

Table III

Spring Characteristics As Affected By The Manner Of Loading
(Experimental Data)

Wire Size	Design of Spring	Activation	Load Deflection Rate	Range of Activation
.016	Vertical Loop (3 mm diameter helix with one and one-half turns)	By unwinding the helix	46 gms/mm	5 - 6 mm
.016	Vertical Loop (3 mm diameter helix with one and one-half turns)	By winding the helix	43 gms/mm	8 - 9 mm

greatest where the bending moment is maximum and it is here that acute bends should be particularly avoided.

In respect to the linear configuration of a spring, it is apparent that optimal design is influenced by the distribution of the wire rather than simply by the total amount of wire utilized.

Spring Activation: During the fabrication of a spring residual stresses may be trapped in the wire. If the spring is reloaded in the same direction as the original bending, the apparent stress to which the spring could be subjected without permanent deformation is considerably higher than the proportional limit for a passive straight wire. Conversely, the maximum load is less than the predicted value if the spring is activated in the opposite direction. This phenomenon can be explained by the presence of residual stress which tends to produce a more uniform stress distribution during proper loading. It also will be found that the load-deflection rate is slightly lowered provided activation is in the same direction as the original bending of the spring. Table III illustrates the difference in range of activation of two identical 10 mm vertical loops with helices having 3 mm diameters and one and one-half turns (Figure 7). It is apparent that springs of this type should be activated in a direction which would tend to further wind the helix. It is pertinent to note that the conventional method of loading a vertical loop is not in this direction and therefore, the full elastic properties of the wire are not utilized.

Clinical Application of Spring Design

A two-step procedure can be suggested for the design of an orthodontic spring. First, on the basis of the physiology of tooth movement and with consideration to accidental loading peaks, a realistic allowable working load is established. Second, the type of alloy, the wire cross section and the linear configuration of the wire are varied so that the spring constant is minimum for the established allowable load. It is apparent that all of the factors that have been considered are not identical in their influence on spring rate and resistance to permanent deformation.

The alteration of the cross-sectional

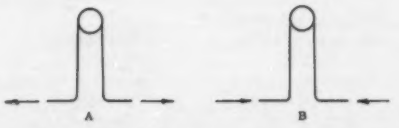

Fig. 7 Direction of spring activation. A) Loading unwinds the helix, B) loading winds the helix. A greater range of activation is found if a spring or vertical loop is activated as in B.

dimensions of a wire produces a dramatic lowering of rate and allowable load. Increasing the length of the wire also reduces the rate, but proportionately the change in the allowable load is less. Finally, additional wire placed where the bending moment is greatest has the ability to reduce the spring gradient without affecting the resistance of the member to permanent deformation. The influence of alloy, wire cross section and linear configuration on spring characteristics is summarized in Table IV.

The design of a spring is not only determined by mechanical factors but is also influenced strongly by inherent limitations within the oral cavity. The vertical height of a spring is limited by the depth of the mucobuccal fold and patient comfort keeps to a minimum the number of turns that can be utilized in a coil. No matter how ingenious the design of an orthodontic spring might be, it is unsuitable for clinical purposes if it is irritating to the soft tissues, unhygienic, uncomfortable or overly complicated to fabricate and use.

To demonstrate some of the possibilities of design, a flat wire spring employed for anterior retraction will be described. The spring has been developed to deliver safely a relatively constant force over a large range of activation.

A jig is used to fabricate the spring in order to minimize the variation in spring characteristics that would result from variable dimensions. The

Table IV

Factors Influencing Spring Rate, Allowable Working Load and Range of Activation

DESIGN FACTOR	LOAD-DEFLECTION RATE	ALLOWABLE WORKING LOAD	RANGE OF ACTIVATION
Mechanical properties of wire	Varies as $\frac{E}{\text{(Modulus of Elasticity)}}$	Varies as $\frac{Sp}{\text{(Proportional Limit)}}$	Varies as $\frac{Sp}{E}$
Wire diameter (Round)	d^4	d^3	$\frac{1}{d}$
Wire Dimension (Rectangular)	bh^3	bh^2	$\frac{1}{h}$
Length (Cantilever)	$\frac{1}{L^3}$	$\frac{1}{L}$	L^2

DESIGN FACTOR	LOAD-DEFLECTION RATE	ALLOWABLE WORKING LOAD	RANGE OF ACTIVATION
Addition of wire without changing length	Decreases	No change	Increases
Activation in direction of original bending	Decreases (slightly)	Increases	Increases
Alteration of cross section to rectangular form	If rate is maintained as a constant	Increases as $\frac{1}{h}$	Increases as $\frac{1}{h}$

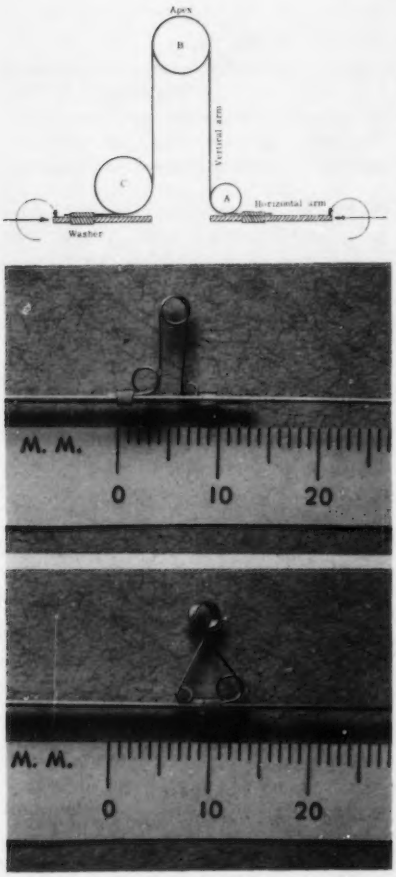

Fig. 8 Upper — The design and method of attachment of the flat wire anterior retraction spring are shown. B — Gingival helix, A and C — occlusal helices. Center — passive spring. Bottom — activated spring.

spring is attached between an .021 x .025 base archwire and the anterior segment by rectangular washers and is activated in the direction shown in Figure 8. It is important to note that a force and a couple are required to activate the member so that the horizontal arms can remain parallel throughout the range of activation. Parallel loading of this type produces a higher rate than simple loading by a force that remains at right angles to the vertical arm. This higher rate must be compensated for by the placement of coils at A and C. The full specifications of the retraction spring are given in Table V. Stainless steel rather than gold has been selected as the alloy of choice since a slightly lower rate could be produced maintaining the same allowable load. However, the spring could be redesigned in gold, using larger cross-sectional dimensions without any marked detrimental effects. The flat wire (.008 x .020) is employed because of its optimal cross section for the achievement of unidirectional bending. The greatest possible height for the vertical arms is desirable for three reasons: 1) the range of parallel activation is increased, 2) it offers an efficient method of lowering rate without excessively decreasing the allowable working load of the member and 3) angular deflection is minimized and hence the rate during parallel displacement of the horizontal arms is lowered. The maximum bending moment in a spring of

Table V

Anterior Retraction Spring Specifications

Alloy	18-8 Stainless Steel
Heat treatment	850° stress relief 3 minutes before winding
Wire cross section	Flat .008 x .020
Height	10 mm or 8 mm
Diameter (large helices)	3 mm
Diameter (small helix)	1.5 mm
Number of turns in helix	(A) 1¼ (B) 2½ (C) 1¼

Table VI

Rate of Ten mm Anterior Retraction Spring

Deflection (mm)	1	2	3	4	5	6	7	8	9	10	11	12
Load (gms)	5	18	34	41	55	65	84	110	124	138	159	184

this design is at the apex of the spring and for this reason, a coil with two and one-half turns is incorporated at this point. The helices at the junction of the horizontal and vertical arms are utilized to compensate for the angular deflection under parallel loading conditions.

Depending upon the depth of the mucobuccal fold, different heights are employed in the flat wire retraction spring. The load-deflection rate for a 10 mm high spring averages 11 gms/mm for the first five millimeters of activation. Since the average rate increases slightly with greater activation, it is preferable to determine the final load by a load-deflection table (Table VI) rather than by multiplying the average rate by the deflection. The spring has a high allowable working load (over 300 gms) and, as expected, possesses a great range of activation (approximately 20 mm). Comparative rates and allowable loads of the flat wire spring and two commonly used vertical loops are presented graphically in Figure 9.

Discussion

The release of relatively constant force has been shown to depend pri-

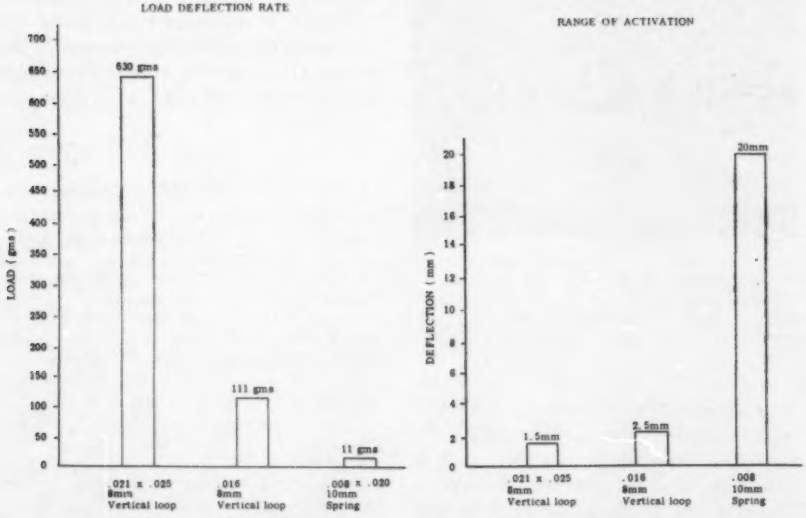

Fig. 9 — Left. The load-deflection rates of an .010 x .020 flat wire anterior retraction spring and two other commonly-used retraction loops are compared. The load represents the force required for each millimeter of spring or loop activation. Right — The range of activation of an .010 x .020 flat wire anterior retraction spring and two other commonly-used retraction loops are compared.

marily on the structural design of the appliance and secondarily on the mechanical properties of the wire. Proper selection and handling of an alloy during spring fabrication are essential, but in no sense will correct unsound mechanical principles employed in design. Since many different alloys may be adapted to appliance fabrication, a thorough understanding of mechanical properties is essential for the design of a satisfactory spring. It is emphasized that a given spring design that is satisfactory in steel should not be fabricated in gold or any other alloy with the expectation that the same characteristics will prevail.

A higher predictability in estimating load-deflection rates and flexibilities under clinical conditions would be assured if wire dimension and quality demonstrated greater standardization. Variation in dimension can significantly influence load deflection rates since rate varies as the fourth power of the diameter (round wire) and as the cube of depth (rectangular wire). Moreover, wires with consistently high proportional limits simplify spring design and minimize the chances of permanent deformation produced by accidental overloading. Any criticism of presently available wire should be tempered with the realization that the weakest link in the development of orthodontic appliances is not to be found in a lack of quality wire but in inadequate structural design.

The importance of spring rate as applied to optimal force values cannot be overemphasized. Two differently designed appliances might deliver an identical force of 150 grams for optimal tooth movement. However, in order to produce 150 grams, a ten millimeter vertical loop of .021 x .025 stainless steel wire requires only a half millimeter of activation, in contrast to a similar vertical loop of .010 x .020 wire which needs to be opened more than four millimeters. Initially the periodontium would be expected to respond similarly to these two springs, but once the tooth has begun to move the responses vary. When the tooth moves a quarter of a millimeter, the .021 x .025 spring will deliver a force of only 75 grams, whereas the .010 x .020 spring will still be delivering about 140 grams after the same deflection. The total distance the .021 x .025 spring can move the tooth with one adjustment is less than one half a millimeter while the .010 x .020 spring is still exerting a force of 130 to 140 grams after one half millimeter of tooth movement.

For this reason, low rate springs which do not rapidly dissipate their stored energy move teeth over greater distances with one adjustment. However, low rate springs can be quite dangerous if they are activated to excessive force levels.

The orthodontic usage of the terms "light" and "continuous" has produced serious semantic difficulties. Various systems and techniques of mechanotherapy have employed this phraseology to describe quite different force quantities and load-deflection rates. Moreover, "light force" has almost an emotional connotation since few orthodontists would want to admit to the use of "heavy force", irrespective of the clinical procedures involved. In order to avoid ambiguity, specific force magnitudes and rates of release should replace vague references to "light" and "continuous" force.

Biologic research is needed to determine optimal force levels and rates for different types of tooth movement. Unless the clinician and the basic investigator have a thorough understanding of appliance design and their force systems, research of this type becomes

haphazard and may lead to fallacious conclusions.

Summary and Conclusions

The biomechanical principles of continuous force delivery in orthodontics have been explored. The confirmation of theoretical considerations by experimental data indicates the possibility of predicting the force characteristics of an appliance by nonempirical methods. A relatively constant force spring for anterior retraction has been described.

1. No spring is completely constant in its action. The most constant forces, at optimal force levels, are derived from springs possessing low load-deflection rates and high allowable working loads.
2. 18-8 stainless steel has a slightly higher maximum load than gold if springs of identical rates are compared. Steel and gold are not interchangeable since the ratio of their moduli of elasticity is 1.8:1.
3. A low temperature stress-relief increases the proportional limit of a cold worked stainless steel wire and thereby, increases its allowable working load.
4. Load-deflection rates can be lowered by reducing the cross-sectional dimension of a wire. For unidirectional loading, the optimum shape for a cross section is rectangular with wire depth at a minimum and width at a practical maximum.
5. The greatest potentiality in altering spring properties is found in the linear configuration of the wire. The placement of additional wire where the bending moment is maximal lowers the rate without changing the maximum load that may be sustained without permanent deformation.
6. Loading a spring in the same direction as it was originally wound increases its elastic range of activation.
7. Although the mechanical properties of a wire partly determine its action, the primary factor in the delivery of continuous force is the design of the spring.
8. Biologic research that aims to determine optimal force levels and rates under varying conditions of tooth movement implies a thorough understanding of the structural design of appliances as well as knowledge of the physiologic process of tooth movement.

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Case Report

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The basal arch, while not a distinct anatomic entity, has been defined by one author as the "apical one third of the alveolus and the bone which supports the alveolar process above the maxillary teeth and below the mandibular teeth[1]." It is the consensus of orthodontic thought that movement of teeth results principally in reshaping the alveolar bony arch with little if any change in the deeper parts of the basal arch. It follows that malocclusions exhibiting disharmonies between maxillary and mandibular basal arches, in either their size or position, place limitations on treatment and have a questionable prognosis.

The patient was a well-developed seventeen year old male. The lower third of the face and the mandible were somewhat larger than average, but they were greatly exceeded in size by the cranial, zygomatic and maxillary areas.

The mandibular dental arch was almost completely within the maxillary. This was due more to difference in the sizes of the basal arches themselves, than to buccal or lingual axial inclinations of teeth in the opposing arches. Only the right first and second molars were in occlusal function; all other mandibular posterior teeth were in complete lingual relation and impinged on the palatal gingiva, as did the lower anteriors, Fig. 1. The malocclusion had caused a pericoronitis in the lower left molar area.

Edgewise bands were placed on all lower teeth, including second molars, and successive round wires were placed for levelling and expansion. In the upper arch, a biteplate was worn to promote bite opening and to prevent tooth contact with lower bands. It carried wire rests over the incisal edges and lower halves of the labial surfaces of the four incisors. This helped prevent irritation and flattening of the gingiva and incisal flaring, commonly resulting from the "settling" of biteplates.

When the maxillary premolars were banded, cross-elastics were worn continuously from the buccal of upper to the lingual of lower premolars.

A passive mandibular edgewise archwire was placed. At subsequent visits progressive mass torque (buccal on the crowns) was placed in the canine, premolar and molar segments. Strang explains the necessity of this, "because when but one torquing twist is placed in the archwire just mesially to the canine tooth of each side, the buccal or lingual tipping force is felt on the canine teeth when their bracket slots are engaged with the wire, but, owing to the fact that they resist this power and so prevent the wire from untwisting, they also automatically remove all of the torque distortion from that part of the archwire that is distal to their brackets. Hence the posterior segment of the edgewise arch simply lies passive in the premolar bracket slots and in the rectangular sheaths of the molar bands instead of exerting the tipping action that is desired[2]."

When this phase of treatment was completed, there was an open anterior bite with the premolars occluding. The buccal segments presented an exaggerated Class II relation with the maxillary second molars occluding in the place of the first molars.

Therefore, the maxillary right and

Fig. 1

Fig. 2

left first molars were extracted and the second molars banded. By means of sectional edgewise arches with closing loops, in conjunction with Class II elastics, the premolars were retracted into the extraction spaces. Following this, the same procedure was used for the canines.

The biteplate was continued through these stages with the added purpose of reinforcing the maxillary molar anchorage. It was discarded when the cuspids were completely retracted. A full edgewise archwire with closing loops distal to the laterals was placed. This had labial crown torque in the incisal segment to prevent an undesirable lingual inclination of the incisors, and Class II elastic force was continued.

Active appliances were in place for three years and two months. Treatment was lengthened by the patient's temporary absences for military service. For the same reason, *no retention* was employed. Figures 2 and 3 show results at the end of active treatment. Patient cooperation, often the deter-

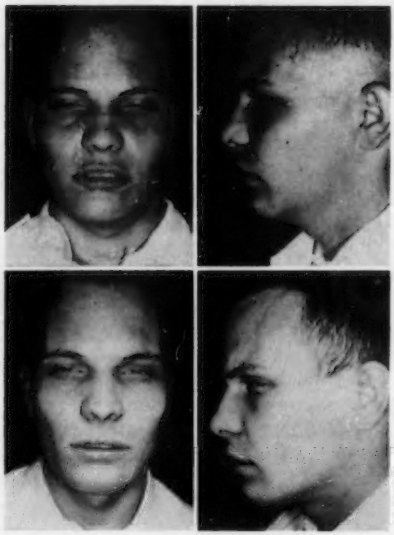

Fig. 3

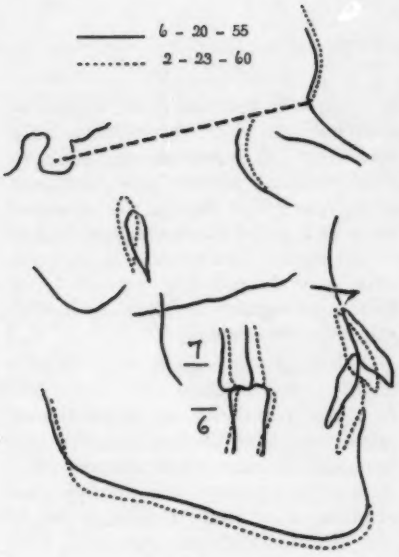

Fig. 4

mining factor in success, was excellent.

A comparison of cephalometric tracings made before treatment and fifteen months after all appliances were removed shows a slight increase in anterior overjet and overbite, Fig. 4. Other areas are stable.

Malocclusions and their correction are three-dimensional problems and, while cephalometrics has proved its value in many areas, one of its shortcomings is its failure to record discrepancies in the horizontal plane and changes made in this plane of space.

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Harmonious Anthropometric Relationships

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Because orthodontists are constantly exposed to disharmony within the mouth and face, a study of harmonious relationships is a prerequisite to the understanding of such disharmonies. We have accepted a relationship of teeth which function efficiently and appear evenly arranged as being good occlusion. Notions of facial harmony have been formed and nourished by the media of advertisements, movies and television. There is a tendency to identify variations from these ideal images as being disharmonious.

When good or normal occlusion exists in a mouth over a period of time there must be physiological balance present. If there are statistically significant relationships between basic facial structures and teeth in these good occlusions, it is probable that these relationships are physiologically essential to good occlusion.

A wrong approach has been made in the evaluation of measurements made possible with lateral cephalograms. The establishment of standard deviations from means is important to the understanding of statistics, but misleading in orthodontics. A study of untreated persons with excellent occlusions shows a wide variation of measurements of many factors within the facial complex Separately, each factor can be studied by listing the measurements numerically. Such a listing, however, does not imply that the people represented at each end, the highest and lowest scores, have occlusions any less acceptable or less normal than those in the middle of such a listing. For instance, if but one person in fifty has excellent occlusion and if but one person in ten thousand is seven feet tall, we could expect to find but one excellent occlusion in a seven foot tall person among five hundred thousand people. This concept is more concrete if we use the measurement of a facial factor rather than one of physique. Understanding of harmony must come through knowing how facial factors fit together and how, or if, they affect one another.

This paper presents a study of harmonious relationships as ascertained from the correlation of measurements taken from headfilm tracings of thirty-two good occlusion cases. Mathematical data on correlations and multiple correlations were secured through use of the IBM 650 electronic computer. Properly used, the derived figures provide good occlusion formulae which can be applied to any case. Orthodontists can match harmonies which exist in the dentofacial complex of good occlusion persons to those of their own patients. This may be done prior to the removal of appliances to ascertain whether patients are ready for retention or need further treatment.

The x-ray films studied are in the files of the University of Washington, Seattle, and are the most recent of a series taken at two-year intervals. Most of the patients were fourteen years of age and both male and female Caucasians were included. The following is quoted from a personal communication from Dr. Alton W. Moore, "The cases were selected by Al Baum and Frank Baird, graduate students at the time. They were selected on the basis of their being normal or good occlusions, and they have maintained their occlusal relationships since that time. No attention

Table I

	Minimal	Maximal	Mean	S.D.
Facial Plane Angle	80	93	86.47	3.35
Angle of Convexity	—9	13	1.75	4.55
AB Plane Angle	—10	2	—4.22	2.88
Mandibular Plane Angle	12	40	25.25	5.71
Y Axis	54	70	60.59	3.93
Occlusal Plane Angle	1	17	9.31	3.73
$\underline{1}$ to $\overline{1}$ Angle	115	145	128.97	6.76
$\overline{1}$ to Mandibular Plane	—8	18	5.78	6.41
$\underline{1}$ to FH Angle	101	120	110.47	5.33
$\underline{1}$ to NA Angle	14	35	22.53	4.75
$\underline{1}$ to NA (mm)	3.5	9.5	5.72	1.52
$\overline{1}$ to NB Angle	16	39	26.47	5.42
$\overline{1}$ to NB (mm)	2	10	5.31	1.85
$\overline{1}$ to FH Angle	41	69	58.75	6.11
Pg to NB (mm)	—1	4.5	2.31	1.33
ANB Angle	0	7	2.31	1.79
$\underline{1}$ to Facial Plane (mm)	1.5	13.5	7.16	2.65
Overbite (mm)	1	6	3.53	1.19

was paid to soft tissue profile in selecting any of these cases."

Table I lists the ranges, means, and standard deviations of eighteen measurements from each of the thirty-two good occlusion cases. Most of the measurements are familiar to users of cephalograms. Two have been added; protrusion is measured in millimeters from the facial plane to the most forward point on the crown of the maxillary central incisor; overbite is measured in millimeters from the tips of the maxillary and mandibular central incisors at right angles to the occlusal plane.

Linear measurements as small as one-half millimeter were used to provide a greater variation where small differences exist.

Figure 1 compares tracings of good occlusion cases with the extreme measurements of the facial plane angle. Table II lists all measurements for these two cases. It is apparent that as the facial plane angle decreases there is an increase in both mandibular and occlusal plane angles. If these changes could be shown to exist throughout the whole sample, negative correlations would be demonstrated. Similarly, as the facial plane angle decreases there is decrease in the angles of both maxillary and mandibular central incisors to FH. If these changes could be shown to exist throughout the sample, positive correlations would be demonstrated.

Perfect correlations from biological material are seldom attained. Among the reasons for these imperfections, insofar as this paper is concerned, are the following:

1. The selection of the good occlusion cases was arbitrary and based upon human judgement.
2. The positioning of the head within a holding device permits some error.

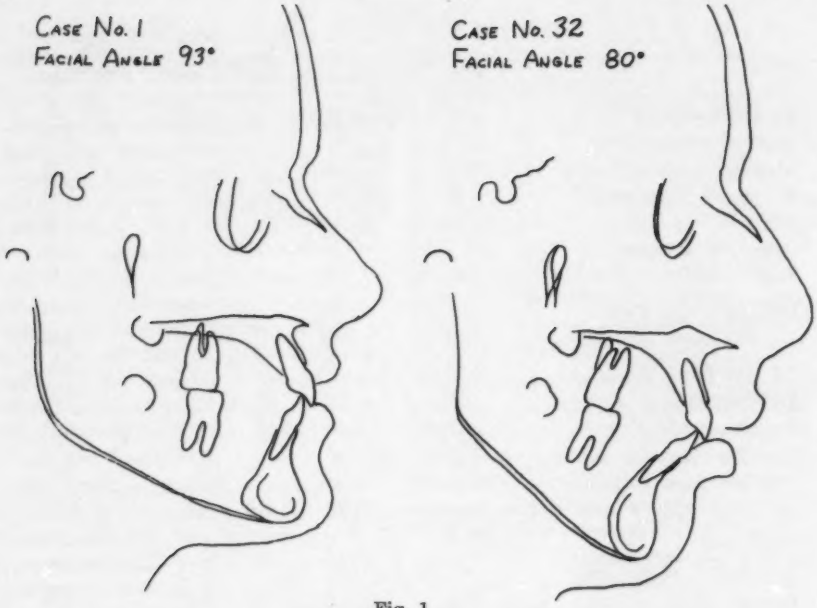


Fig. 1

Table II

CASE NO. 1	AGE 15-5	CASE NO. 32	AGE 13-3
FACIAL ANGLE	93°	FACIAL ANGLE	80°
CONVEXITY	—3°	CONVEXITY	10°
A B PLANE	—3°	A B PLANE	—10°
MANDIBULAR PL	23°	MANDIBULAR PL	40°
Y AXIS	56°	Y AXIS	70°
OCCLUSAL PL	6°	OCCLUSAL PL	16°
$\overline{1}$ TO $\underline{1}$ ANGLE	128°	$\overline{1}$ TO $\underline{1}$ ANGLE	118°
$\overline{1}$ TO MAN. PL.	+3°	$\overline{1}$ TO MAN. PL.	+9°
$\underline{1}$ TO F.H. PL.	116°	$\underline{1}$ TO F.H. PL.	103°
$\underline{1}$ TO NA (°)	24°	$\underline{1}$ TO NA (°)	17°
$\underline{1}$ TO NA (mm)	8 mm	$\underline{1}$ TO NA (mm)	4.5 mm
$\overline{1}$ TO NB (°)	26°	$\overline{1}$ TO NB (°)	38°
$\overline{1}$ TO NB (mm)	5 mm	$\overline{1}$ TO NB (mm)	10 mm
$\overline{1}$ TO FH	64°	$\overline{1}$ TO FH	41°
Pg TO NB	4 mm	Pg TO NB	3 mm
ANB	0°	ANB	6°
$\underline{1}$ TO FAC. PL. (mm)	6 mm	$\underline{1}$ TO FAC. PL. (mm)	12 mm
OVERBITE (mm)	3.5 mm	OVERBITE (mm)	3.5 mm

3. The maturity of the individuals measured was undetermined.
4. Though twelve female and twenty male subjects were measured, they have not been differentiated.
5. Larger millimeter measurements would be anticipated in large persons than in small persons, but no accounting for this effect has been made.
6. The shapes of teeth vary. Steep cusps permit greater closure of the jaws and deeper overbite than flat cusps. This could affect several measurements, but is in no way considered.
7. The tracing and measuring of headfilms are processes subject to error in mechanics and judgement. To limit this error the author performed these operations personally.

Protrusion and retrusion of the teeth affect the profile. Much concern has been expressed over this esthetic effect. Because personal preferences influence treatment results it is important to know if preferences are being substituted for physiologic balance. If correlations exist between facial measurements and dental measurements in this respect, a more subjective approach can be applied.

Figure 2 compares tracings of the good occlusion cases with the extreme measurements for protrusion ($\underline{1}$ to facial plane in millimeters). Table III lists all measurements for these two cases.

The most convenient way to observe a correlation is with a scattergram. Two seemingly related measurements are plotted using these measurements from all the cases in a sample. The ranges are designated vertically for one measurement and horizontally for the other. Casual observation of a scattergram gives an indication of correlation. When there is a definite diagonal pattern to the plotted measurements correlation exists, but where the points representing measurements are scattered at random on the graph there is no correlation. Correlations are mathematically measurable. The term $\underline{r}$ is used for this purpose. If one measurement increases in direct proportion to the other, a perfect correlation of 1.00 is scored. If one measurement decreases in direct proportion to the increase of the other, a perfect negative correlation of -1.00 exists. This is just as valid as a plus score. Where none exists, correlation is measured as 0.00. Technically, this is the mean cross product of standard scores[1].

Figures 3 and 4 demonstrate patterns of both positive and negative correlation. Because some of the angles and distances have greater spread than others, it is necessary to statistically evaluate these graphs. For this purpose the aid of Mr. Charles R. Hebble, professional engineer in hydraulics and member of the American Society of Civil Engineers, was enlisted. In his work Mr. Hebble uses the IBM 650 electronic computer.

The first step taken was to measure the correlation of all 153 possible combinations. Table IV lists these coefficients of correlation.

At this point we are able to select harmonious relationships common to boys and girls fourteen years old, an age at which many are completing orthodontic treatment. By selecting facial factors which are relatively stable and have moderate or high coefficients of correlation, it should be possible to know if any individual presents harmony in these respects. For instance, there is a coefficient of correlation of -.624 between the facial plane angle and the mandibular plane angle.

Figure 5 shows tracings of two cases selected from the practice of the author. Both cases have a facial plane angle of

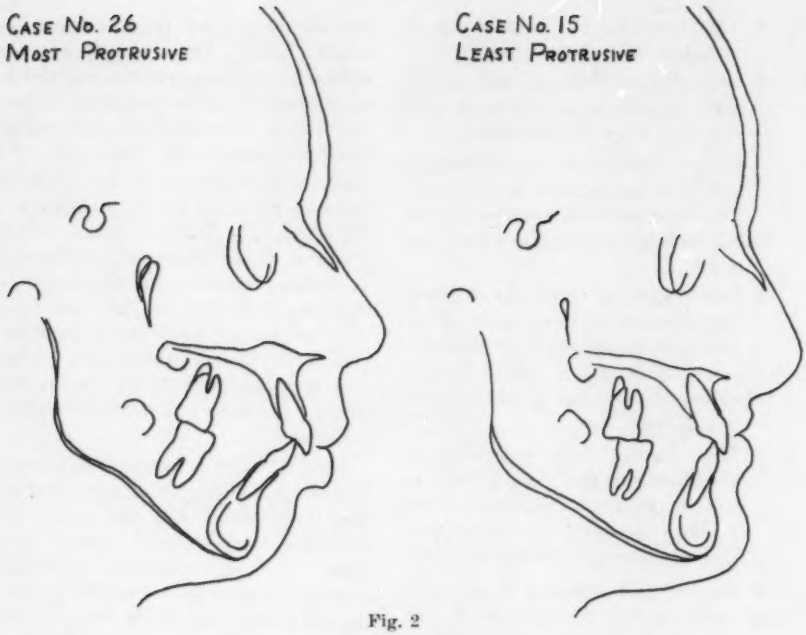


Fig. 2

Table III

CASE NO. 26	AGE 13-4	CASE NO. 15	AGE 15-5
FACIAL ANGLE	83°	FACIAL ANGLE	87°
CONVEXITY	13°	CONVEXITY	—9°
A B PLANE	—10°	A B PLANE	+2°
MANDIBULAR PL	34°	MANDIBULAR PL	24°
Y AXIS	65°	Y AXIS	60°
OCCLUSAL PL	10°	OCCLUSAL PL	5°
$\overline{1}$ TO $\underline{1}$ ANGLE	115°	$\overline{1}$ TO $\underline{1}$ ANGLE	133°
$\overline{1}$ TO MAN. PL.	+9°	$\overline{1}$ TO MAN. PL.	—2°
$\underline{1}$ TO F.H. PL.	112°	$\underline{1}$ TO F.H. PL.	115°
$\underline{1}$ TO NA (°)	23°	$\underline{1}$ TO NA (°)	32°
$\underline{1}$ TO NA (mm)	5 mm	$\underline{1}$ TO NA (mm)	4 mm
$\overline{1}$ TO NB (°)	36°	$\overline{1}$ TO NB (°)	16°
$\overline{1}$ TO NB (mm)	10 mm	$\overline{1}$ TO NB (mm)	2 mm
$\overline{1}$ TO FH	47°	$\overline{1}$ TO FH	69°
Pg TO NB	1 mm	Pg TO NB	3 mm
ANB	7°	ANB	2°
$\underline{1}$ TO FAC. PL. (mm)	13.5 mm	$\underline{1}$ TO FAC. PL. (mm)	1.5 mm
OVERBITE (mm)	4 mm	OVERBITE (mm)	3.5 mm

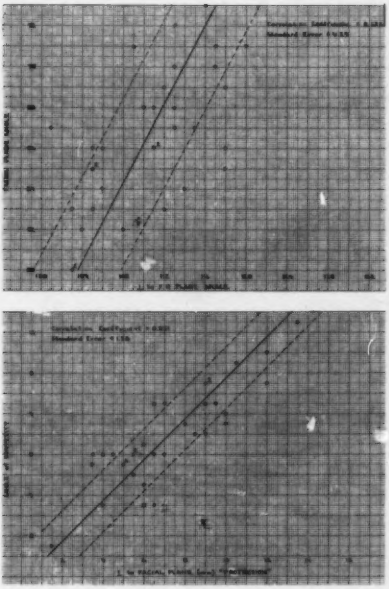


Fig. 3. Positive correlations. Above—Facial plane with 1 to FH. Below—Convexity with $\underline{1}$ to Facial $\overline{\text{plane}}$.

87 degrees. Where standard error would indicate a variation in mandibular plane angle from 17 degrees to 31 degrees, one of these cases presents a mandibular plane angle of but 10 degrees while the other has a 36 degree angle. This is but one type of facial disharmony.

Another disharmony can exist between the angle of convexity and Pg to NB (mm) or chinbutton. Figure 6 compares tracings of two patients selected from the practice of the author who present different aspects of this disharmony. The standard error indicates, in a case with 4 millimeters of chinbutton, an angle of convexity of from 3 degrees to -5 degrees, but this case presents a 12 degree angle of convexity. The other case presents a chinbutton measurement of -1 millimeter. The standard error indicates a variation in the angle of convexity of from 3 de-

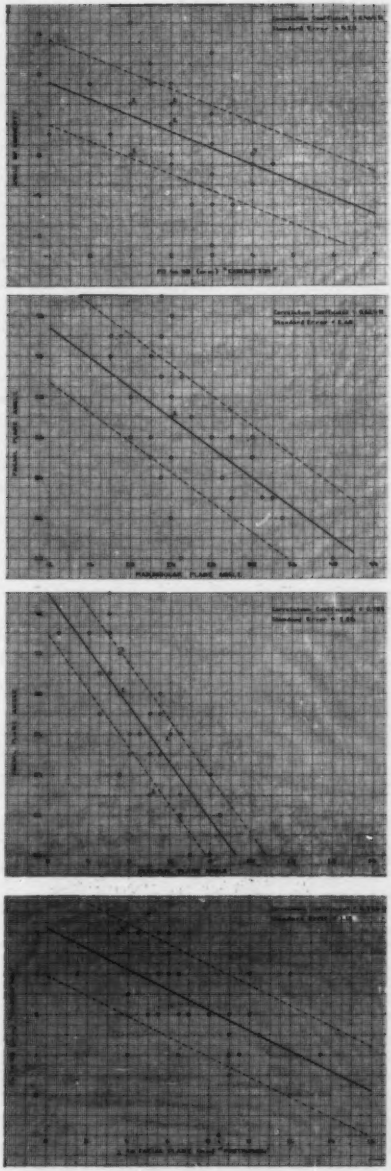


Fig. 4. Negative correlations. Top to bottom—convexity with Pg to NB; facial plane with mandibular plane; facial plane with occlusal plane and Pg to NB with $\underline{1}$ to facial plane.

Table IV

	FAC. PL. (o)	CONVEXITY (o)	AB PL. (o)	MAND. PL. (o)	Y AXIS	OCCLUSAL PL. (o)	1 TO $\bar{1}$ (o)	$\bar{1}$ TO MAND.PL.(o)	1 TO FH (o)	1 TO NA (o)	1 TO NA (mm)	$\bar{1}$ TO NB (o)	$\bar{1}$ TO NB (mm)	$\bar{1}$ TO FH (o)	Pg TO NB (mm)	ANB (o)	1 TO FAC. PL.(mm)	OVERBITE (mm)
FAC. PL. (o)																		
CONVEXITY (o)	.269-																	
AB PL. (o)	.116	.825-																
MAND. PL. (o)	.624-	.374	.083-															
Y AXIS	.854-	.353	.086-	.723														
OCCLUSAL PL. (o)	.789-	.347	.103-	.702	.790													
1 TO $\bar{1}$ (o)	.016	.342-	.281	.046	.029-	.178												
$\bar{1}$ TO MAND. PL. (o)	.014-	.264	.457-	.487-	.097	.218-	.602-											
1 TO FH (o)	.626	.192-	.178	.441-	.478-	.624-	.476-	.125										
1 TO NA (o)	.167	.608	.556	.292-	.303-	.420-	.359	.048	.633									
1 TO NA (mm)	.092	.347-	.442	.134-	.093-	.284-	.376-	.146	.370	.491								
$\bar{1}$ TO NB (o)	.091-	.655	.560-	.182	.179	.069	.818-	.628	.096	.189-	.146							
$\bar{1}$ TO NB (mm)	.401-	.757	.501-	.538-	.511	.308	.620-	.261	.061-	.275	.173	.762						
$\bar{1}$ TO FH (o)	.597	.617-	.546	.446-	.575-	.430	.669	.562-	.278	.220	.049	.821-	.773-					
Pg TO NB (mm)	.137	.483-	.065-	.408-	.350-	.326-	.074	.271	.034	.192	.015	.201	.425-	.095				
ANB	.289-	.832	.810-	.343	.298	.182	.316-	.232	.156-	.476-	.430-	.528	.667	.552-	.172-			
1 TO FAC. PL. (mm)	.298-	.851	.579-	.400	.399	.235-	.567-	.296	.016	.355-	.139	.750	.928	.687	.526-	.690		
OVERBITE (mm)	.068-	.214	.507-	.349-	.200	.162-	.031-	.484	.082-	.201	.131-	.091	.027-	.164-	.412	.338	.140	

CORRELATION COEFFICIENTS
IBM 650 Data

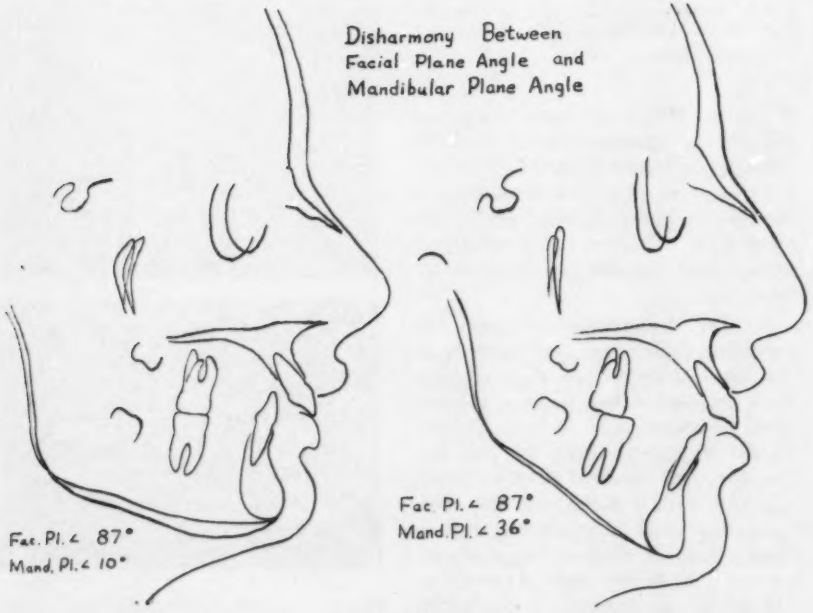


Fig. 5

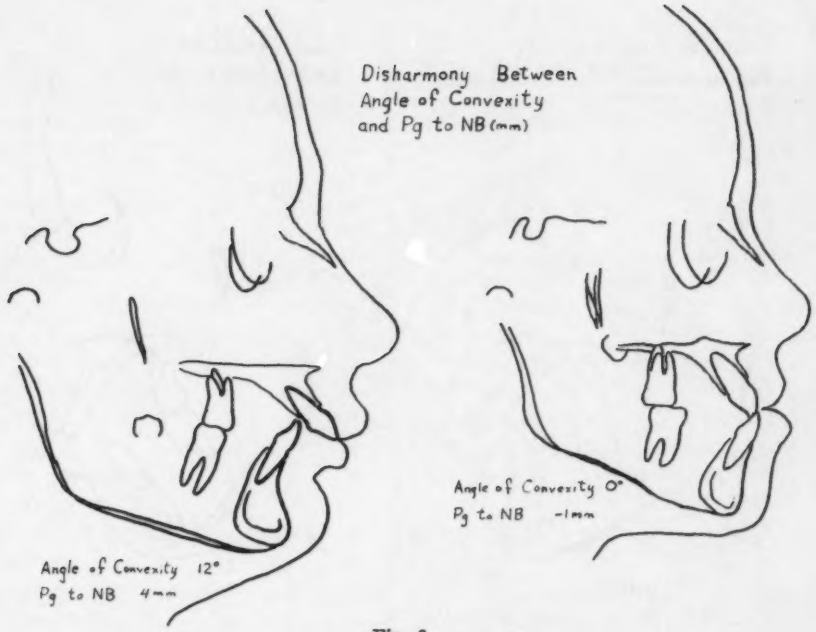


Fig. 6

grees to 11 degrees. Instead the angle of convexity reading is but zero degree.

Figures 5 and 6 each represent a type of disharmony. Both might be found in any patient, along with numerous others unexplained here. Table IV lists fifty-six coefficients of correlation with moderate scores (±.40 to ±.79) and eight with high scores (±.80 to ±1.00). Some of these represent different ways of measuring the same thing. Others, however, measure harmonious relationships which should represent goals in orthodontic treatment evaluation. Using basic anatomical landmarks these harmonies might also be adapted to the practice of prosthodontics.

First Method of Evaluation

One method of orthodontic diagnosis and treatment evaluation devised here uses scattergrams on which the line of regression, along with the lines representing standard errors, is present. This line of regression is drawn to the slope of the line of best fit. It is mathematically determined. Mr. Hebble calculated the slope of these lines as well as the standard errors.

Six scattergrams representing combinations of seven facial and dental measurements were selected (Figures 3 and 4). This group of seven measurements was intended to represent some which are but slightly affected by orthodontic treatment (facial plane angle and mandibular plane angle), some which moderately change with orthodontic treatment (angle of convexity, Pg to NB (mm) and occlusal plane angle), and some which change considerably with orthodontic treatment (1 to FH

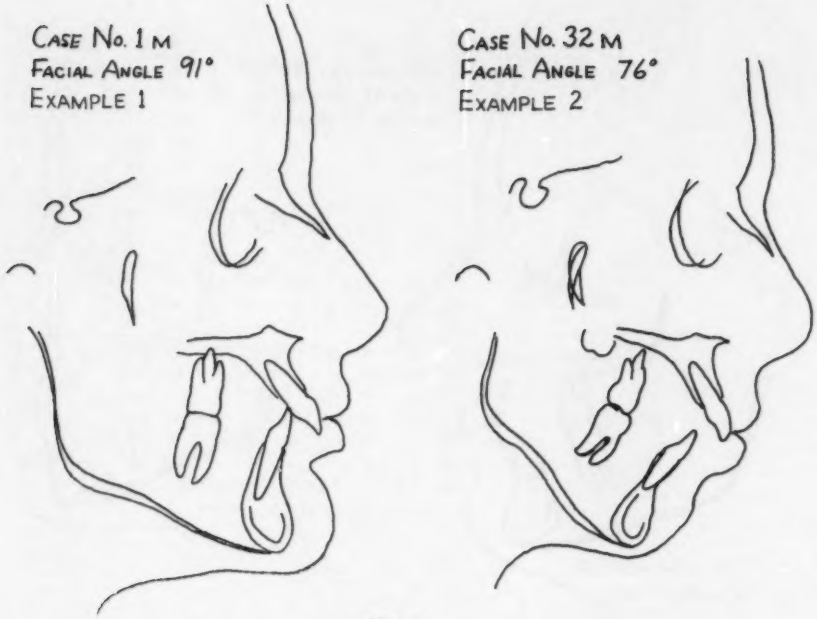

CASE No. 1 M
FACIAL ANGLE 91°
EXAMPLE 1
CASE No. 32 M
FACIAL ANGLE 76°
EXAMPLE 2

Fig. 7

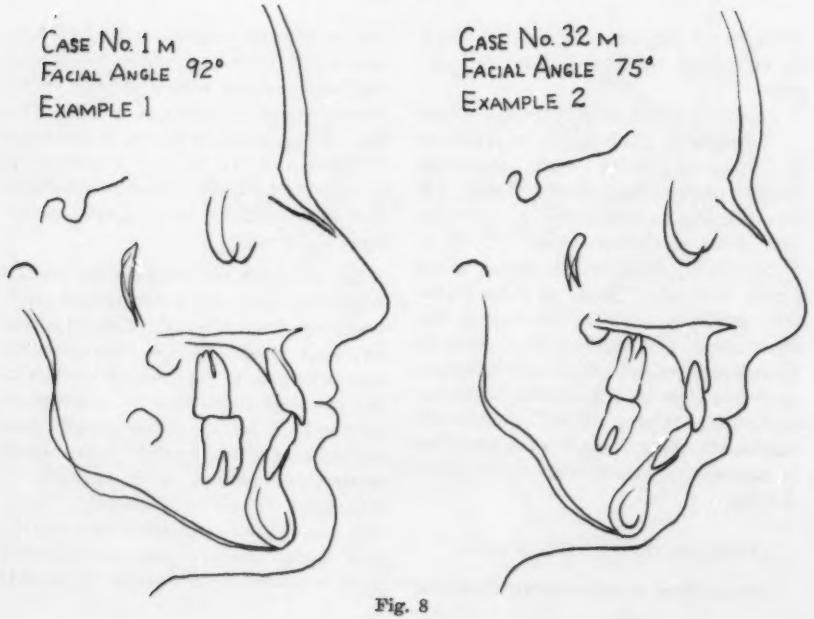

CASE No. 1 M
FACIAL ANGLE 92°
EXAMPLE 1
CASE No. 32 M
FACIAL ANGLE 75°
EXAMPLE 2

Fig. 8

Table V

CASE NO. 1M				CASE NO. 32M			
Example 1	AGE 12-4	13-5	14-8	Example 2	AGE 16-4	17-3	17-8
FACIAL ANGLE	91	91	92	FACIAL ANGLE	76	74	75
CONVEXITY	3	—2	—3	CONVEXITY	12	12	12
A B PLANE	—9	—2	—4	A B PLANE	—9	—9	—8
MANDIBULAR PL	21	22	20	MANDIBULAR PL	44	46	44
Y AXIS	57	58	57	Y AXIS	73	76	74
OCCLUSAL PL	4	—1	1	OCCLUSAL PL	15	9	21
$\overline{1}$ TO $\underline{1}$ ANGLE	123	137	132	$\overline{1}$ TO $\underline{1}$ ANGLE	110	129	139
$\overline{1}$ TO MAN. PL.	0	—3	3	$\overline{1}$ TO MAN. PL.	—2	—14	—4
$\underline{1}$ TO F.H. PL.	126	115	115	$\underline{1}$ TO F.H. PL.	113	108	91
$\overline{1}$ TO NA (°)	32	25	25	$\overline{1}$ TO NA (°)	31	27	9
$\overline{1}$ TO NA (mm)	9	9	8	$\overline{1}$ TO NA (mm)	10	8	2
$\overline{1}$ TO NB (°)	20	17	23	$\overline{1}$ TO NB (°)	26	15	29
$\overline{1}$ TO NB (mm)	4	4.5	6	$\overline{1}$ TO NB (mm)	9	6	8
$\overline{1}$ TO FH	69	71	67	$\overline{1}$ TO FH	48	58	50
Pg TO NB	4	4.5	5	Pg TO NB	1.5	1	2
ANB	4	1	1	ANB	7	7	7
$\underline{1}$ TO FAC. PL. (mm)	11.5	7	5.5	$\underline{1}$ TO FAC. PL. (mm)	18.5	17.5	11
OVERBITE (mm)	9	5	4.5	OVERBITE (mm)	1	0	2

angle and $\underline{1}$ to facial plane (mm)).

To demonstrate this method thirty-two consecutively treated cases were taken from the practice of the author for evaluation. The only criterion in the selection of these cases was that each required complete maxillary and mandibular banded appliance therapy. They were treated *before* these coefficients of correlation had been calculated.

From these thirty-two cases the extremes in facial plane angle and protrusion were picked to see how treatment had affected the six relationships mentioned above. Because extreme cases were involved it became necessary to repeat these scattergrams on a larger scale to include the greater spread.

The case with the greatest facial plane angle is labeled example 1 and the case with the least facial plane angle is labeled example 2. Figure 7 shows tracings before treatment and can be compared with Figure 8 which shows tracings of examples 1 and 2 after treatment. Table V compares measurements for examples 1 and 2.

The case with the most protrusion is labeled example 3 and the case with the least protrusion is labeled example 4. Figure 9 shows tracings before treatment and can be compared with Figure 10 which shows tracings of examples 3 and 4 after treatment. Table VI compares measurements for examples 3 and 4.

Figure 11 is the first extended scattergram on which the effects of treatment for these four example cases have been plotted. Because the facial plane angle and the mandibular plane angle change but little, the most to be gain-

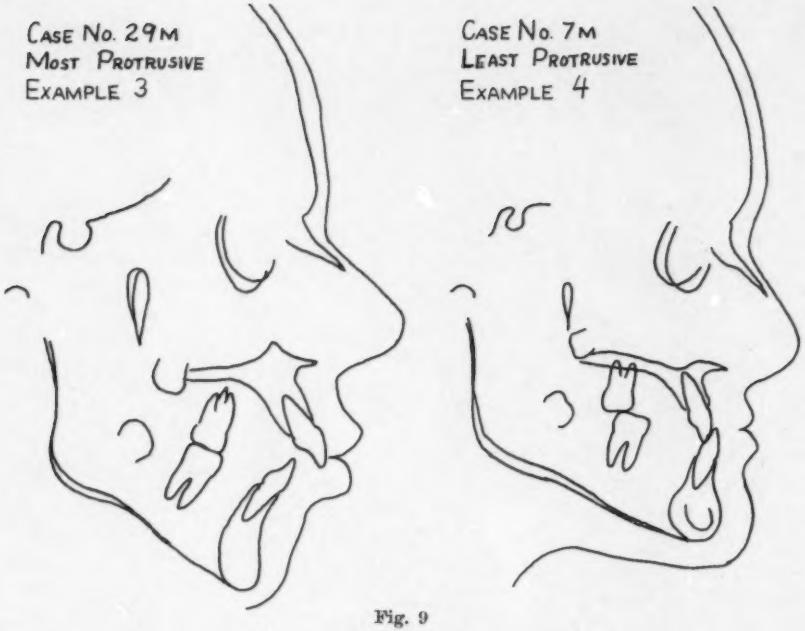

CASE No. 29M
MOST PROTRUSIVE
EXAMPLE 3
CASE No. 7M
LEAST PROTRUSIVE
EXAMPLE 4

Fig. 9

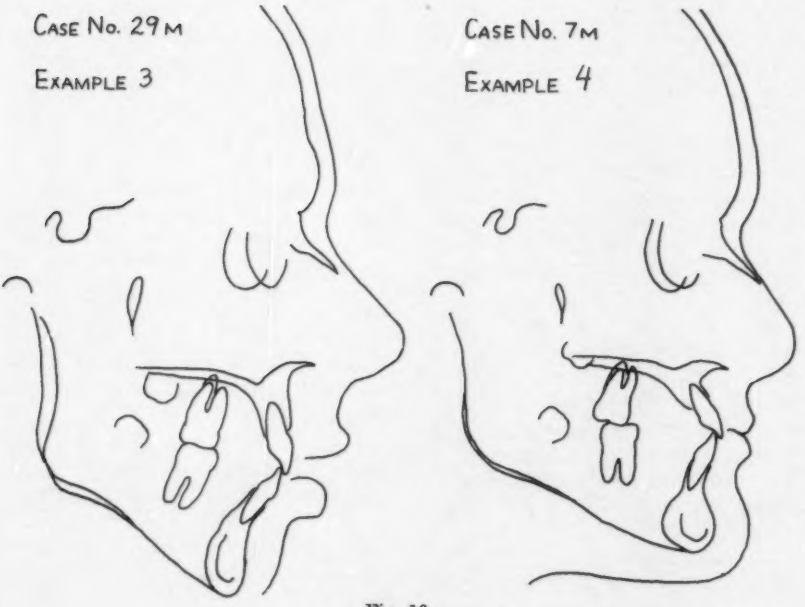

CASE No. 29M
EXAMPLE 3
CASE No. 7M
EXAMPLE 4

Fig. 10

Table VI

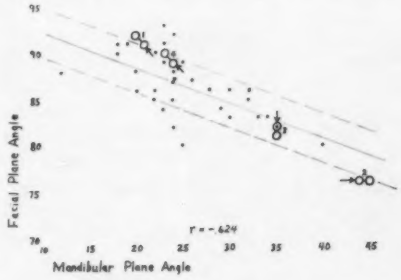
CASE NO. 29M			
Example 3 AGE	15-3	16-6	17-6
FACIAL ANGLE	82	82	82
CONVEXITY	9	8	10
A B PLANE	—6	—6	—7
MANDIBULAR PL	35	34	34
Y AXIS	64	65	66
OCCLUSAL PL	8	10	16
$\bar{1}$ TO $\underline{1}$ ANGLE	109	123	132
$\bar{1}$ TO $\underline{\text{MAN. PL.}}$	8	—1	+1
$\underline{1}$ TO F.H. PL.	118	115	102
$\bar{1}$ TO NA (°)	31	27	15
$\bar{1}$ TO NA (mm)	12	12	2.5
$\bar{1}$ TO NB (°)	33	24	27
$\bar{1}$ TO NB (mm)	9	7	8.5
$\bar{1}$ TO FH	48	57	55
Pg TO NB	2	1	1
ANB	5	5	6
$\underline{1}$ TO FAC. PL. (mm)	19	19	10
$\underline{\text{OVERBITE}}$ (mm)	1	2	1.5

CASE NO. 7M			
Example 4 AGE	12-2	13-5	13-8
FACIAL ANGLE	89	90	90
CONVEXITY	—16	—17	—12
A B PLANE	+6	+5	+2
MANDIBULAR PL	24	24	23
Y AXIS	58	58	57
OCCLUSAL PL	15	5	4
$\bar{1}$ TO $\underline{1}$ ANGLE	141	120	127
$\bar{1}$ TO $\underline{\text{MAN. PL.}}$	—5	—5	—1
$\underline{1}$ TO F.H. PL.	109	137	121
$\bar{1}$ TO NA (°)	28	50	33
$\bar{1}$ TO NA (mm)	6	11.5	9
$\bar{1}$ TO NB (°)	17	15	20
$\bar{1}$ TO NB (mm)	1	2	3
$\bar{1}$ TO FH	70	72	68
Pg TO NB	3	5	5
ANB	—5	—6	—3
$\underline{1}$ TO FAC. PL. (mm)	—3	1	1.5
$\underline{\text{OVERBITE}}$ (mm)	6	2.5	1

ed from this graph is the observation that all four examples lie close to, or within, one standard error of the line of regression which represents a basic facial harmony.

Figure 12 is the extended scattergram showing the correlation of the angle of convexity with Pg to NB (mm) or the amount of chinbutton. These measurements have been affected more by treatment than those in Figure 11, particularly examples 1 and 4.

Figure 13 shows the extended scattergram plotting the facial plane angle and the occlusal plane angle. While the facial plane has remained quite constant, the occlusal plane angle has improved in all but example 1 where it maintained good relationship.



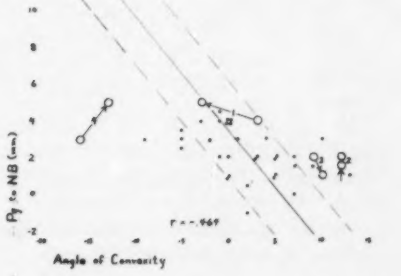


Fig. 11—above
Fig. 12—below

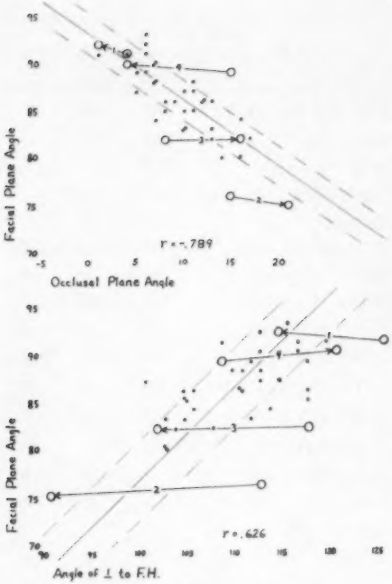


Fig. 13—above
Fig. 14—below

Figure 14 is the extended scattergram which shows the correlation of the facial plane angle with the angle of $\underline{1}$ to the FH. Great change in the angle of the maxillary central incisor is evident. Examples 1 and 3 have improved in this relationship, but example 4 worsened and example 2 changed from one extreme to the opposite.

Figures 15 and 16 represent two different ways of comparing the amount of protrusion these four examples presented before and after treatment, and whether or not harmony was achieved in these aspects. Example 1 had an increase in the amount of chinbutton which offset the reduction in protrusion so that no improvement is noted in Figure 15. However, a reduction in the angle of convexity improves the position of example 1 on Figure 16.

Speculation upon protrusion becomes interesting in the light of these correlated facial factors. Both the angle of convexity and chinbutton change to some degree with the bodily movement of the roots of the anterior teeth. The retraction of these roots affects these measurements in the way that extraction would, but to a lesser degree. At some undetermined points these changes cease and the true junction of alveolar crest with basal bone becomes evident. These points probably represent optimums insofar as Downs' points A and B are concerned.

If one considers the muscle attachments at the base of the nose and upon the symphysis of the mandible, a concept of protrusion emerges. The close attachment of the facial musculature above apparently limits protrusion in the thirty-two good occlusion cases measured, leading to the high coeffi-

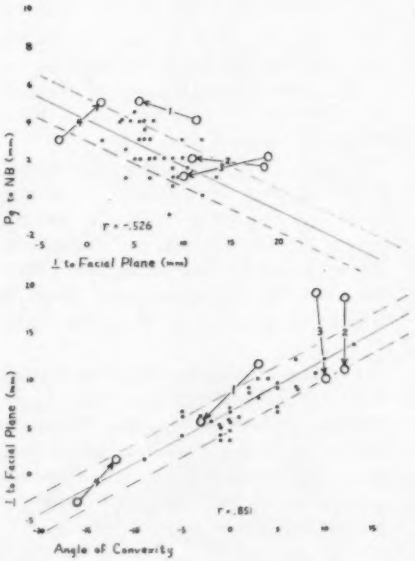


Fig. 15—above
Fig. 16—below

cient of correlation (.851) between the angle of convexity and $\underline{1}$ to facial plane (mm). Similarly, there is a moderate negative coefficient of correlation (—.526) between Pg to NB (mm) and $\underline{1}$ to facial plane (mm), but several factors enter into this relationship. It might be argued that an increase in Pg to NB (mm) moves one end of facial plane forward, but this is refuted by low coefficient of correlation (.157) between Pg to NB and the facial plane angle. Evidently the tilting of the mandible with an increase in the mandibular plane angle negatively affects Pg to NB (mm) as indicated in the moderate negative coefficient of correlation (—.408) between these factors. In our second method of evaluation this effect will be measured and accounted for. It would seem that Pg to NB measures facial muscle pressure, for an increase of Pg to NB of one millimeter corresponds to a decrease in protrusion, $\underline{1}$ to facial plane (mm), of approximately four millimeters.

The above system of evaluating measurements for a case is often all that is necessary to establish concepts of harmonious relationships. By definition, however, only about sixty-eight percent of the cases lie within a standard error of the regression lines in a scattergram. All cases were selected for their good occlusions and therefore must be explained in any valid system of diagnosis using them as criteria. Multiple correlation or multiple regression equations do this.

Where correlations exist between different parts of the face and the teeth, it is reasonable to suspect that the position of the teeth depends upon the facial construction. Some correlations are statistically more significant to tooth position than others. Multiple correlation is a mathematical process which explains variance. Using a stepwise procedure it eliminates irrelevant factors and measures others in proportion to their contribution in a variance. In this case the factors are measurements of facial parts and the variance is of tooth position.

Second Method of Evaluation

A mathematical process combining ten separate steps to work as a single solution was devised. Eight of the eighteen measurements from Table I were selected as basic and least affected by tooth movement. These were as follows:

1. Facial plane angle
2. Angle of convexity
3. AB plane angle
4. Mandibular plane angle
5. Y axis
6. Occlusal plane angle
7. Pg to NB (mm)
8. ANB angle

These eight factors were separately analyzed with each of the remaining ten tooth measurements to arrive at equations which best explain their variance and interacting effects.

As a result, good occlusion equations have been established to determine ten separate measurements for tooth positions. The measurements are ideal, representing harmonious anthropometric relationships presented by the sample of thirty-two good occlusion cases. Table VII is a key to the formulae, found in Table VIII, which provides mathematical solutions for harmonious angulation and anteroposterior positioning of the maxillary and mandibular central incisors.

Table VIII groups ten $\underline{y}$ (dental measurement) lists. Each list contains those $\underline{x}$ values which are statistically significant in the determination of the desired $\underline{y}$ measurement, as well as a constant (K) for that $\underline{y}$ measurement.

Table VII

Key to Good Occlusion Equations

X1 Facial Plane Angle	y1 $\overline{1}$ to $\underline{1}$ Angle
X2 Angle of Convexity	y2 $\overline{1}$ to Mandibular Plane Angle
X3 AB Plane Angle	y3 $\underline{1}$ to F.H. Angle
X4 Mandibular Plane Angle	y4 $\underline{1}$ to NA Angle
X5 Y Axis	y5 $\underline{1}$ to N.A. (mm)
X6 Occlusal Plane Angle	y6 $\overline{1}$ to N.B. Angle
X7 Pg to NB (mm)	y7 $\overline{1}$ to NB (mm)
X8 ANB Angle	y8 $\overline{1}$ to F.H. Angle
K Constant	y9 $\underline{1}$ to Facial Plane (mm)
± Standard Error	y10 Overbite (mm)

Table VIII

Good Occlusion Equations

y1		y2		y3	
X1	.75	X1	—1.33	X1	.56
X2	—2.72	X2	2.10	X2	1.21
X3	—3.09	X3	1.14	X3	1.87
X6	1.39	X4	—.85	X6	—.71
X7	—3.56	X6	—.77	X7	1.53
K	51.31±6	X7	2.92	K	71.23±4
		X8	—1.44		
		K	147.06±4		

y4		y5		y6	
X1	—1.02	X1	—.29	X2	2.34
X2	.03	X2	.69	X3	1.66
X3	.82	X3	.84	X5	.30
X5	—.39	X6	—.40	X6	—.64
X6	—.86	X7	.86	X7	2.76
X8	—.26	X8	—.70	X8	—1.00
K	145.99±3.5	K	36.61±1	K	13.15±4

y7		y8		y9	
X1	—.13	X1	1.31	X1	—.32
X2	.75	X2	—2.16	X2	1.16
X3	.72	X3	—1.17	X3	.84
X4	.09	X4	—.21	X4	.07
X5	.10	X6	.82	X6	—.46
X6	—.30	X7	—3.06	X7	.67
X7	.77	X8	1.59	X8	—.38
K	10.47±1	K	—54.48±3.5	K	38.18±1

y10	
X1	—.26
X3	—.21
X4	—.09
X5	—.16
X7	.13
K	36.90±1

Use of Good Occlusion Equation y3 to determine the Ideal Angle of 1 to F.H. for Example 2

	measurements for		multiplied by		
x1	Facial Plane Angle	75	.56	42.00	
x2	Angle of Convexity	12	1.21	14.52	
x3	AB Plane Angle	-8	1.87		-14.96
x6	Occlusal Plane Angle	21	- .71		-14.91
x7	Pt. to NB (mm)	2	1.53	3.06	
K	Constant 71.23±4			+ 59.58	-29.87 = 100.94±4

for Example 4

x1	90 · .56	=	50.40		
x2	-12 · 1.21	=		-14.52	
x3	2 · 1.87	=	3.74		
x6	4 · - .71	=		- 2.84	
x7	5 · 1.53	=	7.75		
K	71.23±4	+	61.89	-17.36	= 115.76±4

Fig. 17

To solve an equation for a given case it is necessary to multiply these x values by the corresponding facial measurements found in the key (Table VII). The sum of these products added to the constant in each group represents an ideal dental measurement.

A practical example of combining the above two methods for evaluating treated cases would be as follows:

In Figure 14 it was noted that for examples 2 and 4 the angles of 1 to FH were outside the standard error at completion of treatment. To know if these variations were due to factors which accounted for variance among the good occlusion cases the formula for 1 to FH angle (y3) should be applied. Figure 17 demonstrates these applications.

Good occlusion equation y3 indicates that for example 2 the proper angle is 101±4 degrees rather than the 91 degrees it is. For example 4 the proper angle is 115±4 degrees rather than the 121 degrees at completion of treatment. An examination of the headfilm for example 2 shows that the root of the maxillary central incisor was almost through the palatal plate of bone when treatment ceased. This might be a limitation over which no control exists. In example 4 the high angle of 1 to FH is out of harmony with the dentofacial complex. If protrusion, as measured by 1 to facial plane (mm) is also too large, this might have been an extraction case. The good occlusion equation y9 provides this information, as demonstrated in Figure 18.

This calculation indicates that for this least protrusive example harmony is achieved with a 1 to facial plane (mm) measurement of 1.40±1 millimeters. The treatment result of 1.5 millimeters is correct for this case. The angle of the maxillary central incisor to the FH, in this example, is the re-

Use of Good Occlusion Equation y9 to determine Ideal Protrusion for EXAMPLE 4

X1	90	·	-.32	=		-28.80	
X2	-12	·	1.16	=		-13.92	
X3	2	·	.84	=	1.68		
X4	23	·	.07	=	1.61		
X6	4	·	-.46	=		-1.84	
X7	5	·	.67	=	3.35		
X8	-3	·	-.38	=	1.14		
K	38.18±1			+	7.78	-44.56	= 1.40±1

Fig. 18

sult of an extremely negative angle of convexity which would indicate lack of maxillary forward development.

If the incisor teeth can be positioned within the profile in harmony with surrounding structures, they should be stable and esthetically correct. Esthetics is the science of beauty and taste[2]. It is scientifically more correct to use relationships between measurable landmarks for the positioning of the teeth than to use averages or preconceived notions. For practical purposes, the equations to determine the angle and the anteroposterior position of the maxillary central incisor (y3 and y9) are most useful because they are important esthetically. If these check with treatment results after good occlusal relationships are established and if arch form has not been violated, the same harmonies are present as those found in the group of selected good occlusion cases.

These methods of evaluation may not be based upon the best possible facial or tooth measurements, but as methods they are statistically sound. Different measurements or ways to reduce the reasons for imperfection of correlations listed previously might bring greater significance to these harmonies. Harmonious relationships might vary with age, sex or racial differences but, as biological correlations with statistical significance, they indicate that such variations should be consistent and measurable.

Classification of malocclusion might be made according to deviation from harmonies and might be measurable. Hereditary deviations from harmonious relationships might be shown to exist.

The use of the above scattergrams and good occlusion equations provide new and useful methods for orthodontic complex.

Baker Building

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Clinical Management And Supportive Rationale In Early Orthodontic Therapy

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Orthodontic therapy, not unlike that seen in other health fields, is subject to extreme shifts and even fads. The basic underlying theme of prevention so characteristic to modern medicine and dentistry was set aside in a large segment of orthodontic practice in past years in favor of a philosophy of so-called watchful waiting. This type of thinking held the results of deciduous and mixed dentition treatment to be of questionable value in terms of total gain for the patient. On the other hand, incipiencies of Class III malocclusion and presence of anterior and posterior crossbites seem to have always found an acceptance for immediate treatment as soon as presented to the orthodontist. These latter categories represent a relatively small segment of the total incipiencies of malocclusion. We might ask ourselves the reasons why most orthodontists preferred (and indeed some still prefer) to watch a malocclusion develop before instituting corrective therapy. Broadly speaking, the answer is simple. Most cases required additional treatment in the early permanent dentition or had collapsed or progressed beyond the earlier malocclusion as a result of untoward tooth movement and mandibular positioning. This discouraging state of affairs has been improving to the extent that early treatment (this usually means the mixed dentition) is being reported with increasing frequency in the current literature. The picture of malocclusion is still the same, the appliances are essentially the same, and we still know that it is preferable to prevent malocclusion rather than treat a full-blown dentofacial anomaly. Obviously, we are undergoing change in treatment timing.

I like to think that our treatment efforts are being directed more and more along a line that takes active cognizance of the fact that the dental apparatus and its supporting tissues are truly dynamic structures subject to the same rules applying to all body tissues. All too often we follow one authority or another in blind fashion in total ignorance of the validity of rationale that had led him into some particular series of mechanical maneuvers. Some of their statements taken in part and applied to clinical thinking have led to stereotyped practice procedures which are faulty to say the least. All too often these alleged "philosophies of treatment" treat the teeth as if they were inanimate objects in an equally inanimate supporting structure. We are still prone to stand in admiration of the orthodontist who is able to effect tooth movement over considerable distance in beautifully controlled fashion and pay little or no attention to work in which an incipient malocclusion was intercepted and prevented with minimal appliance therapy. In truth, as members of a health profession, we should be ashamed that malocclusion is allowed to progress to a place where heroics become necessary.

As the title indicates, the present paper is concerned with the clinical management of early malocclusion. Representative, and I hope illustrative,

Read before the Northern California component of the Angle Society, May, 1959.

cases will be presented in support of the rationale which underlies my thinking in treatment therapy. I make no apology in stating my continuing effort to correlate my orthodontic mechanics with tissue biology and physiology. The orthodontic literature is replete with mechanics of the variety advocating rectangular wire adjustments of the "thickness of a thin dime," applying forces to a single tooth far beyond tissue tolerance, reciprocal forces which the operator hopes will not act in reciprocal fashion, and mechanotherapy which is dignified by cephalometry and ignores the theme of endless variation in facial morphology.

On the other hand, our literature and that of ancillary fields have supplied us with the fruits of excellent research which the orthodontist may use and apply to his treatment mechanics; work serving as guideposts telling us over and over that we are dealing with a biological structure. The obvious corollary is that movement of teeth and the resultant correction of dentofacial anomaly will be more satisfactory if we treat both soft and hard tissue with care and respect for their physiologic integrity.

The overwhelming bulk of research evidence points very clearly to a genetic origin for most malocclusions. Figure I shows the pretreatment photographs of a mother and her daughter, both presenting with Class II malocclusions and lacking in lower face height. One would expect a more favorable treatment result with the daughter in whom facial growth has not been completed. This is borne out in the posttreatment photographs. As clinicians, we are forced to deal with whatever nature has endowed the patient in the way of inherited dentofacial characteristics. We are all products of the inheritance upon which is superimposed the sum total of intra and extrauterine environment. It is unfortunate that Brodie's serial growth

Fig. 1 Beginning and posttreatment photographs of a mother and daughter showing marked similarity in dentofacial complex. Note the greater degree of facial improvement in the daughter over that gained for the mother.

study was interpreted widely to mean that once the morphogenetic facial pattern was established nothing could be done about it. The mean and other statistical values of central tendency have their place as they did in Brodie's work and will continue to serve us well, but not if their significance is poorly understood. All too often we stand in blind obeisance before the throne of the "average value," applying it to the single individual. Stating it more exactly, we try to fit the single individual to the average value which somewhere along the line has also become the standard of excellence. Dewel[1] is quite cognizant of the problem in terms of facial esthetics by taking issue with those who would standardize the profile by geometry applied to the dental apparatus. He states "It is possible that the straight profile has been overemphasized in our current concept of pleasing facial contours and that this has led to premature serial extraction as a pretreatment requirement. Yet there was a time when this convex facial type was considered to be the essence of beauty. Even casual study of the paintings of the great Renaissance artists shows that they favored models with slightly recessive chins and foreheads that tapered backward as well as upward. The most famous example of this concept in beauty is, of course, the Mona Lisa. In a previous age, the prominent Roman nose and the Greek profile were considered a mark of distinction, yet they also could be in harmony with other facial structures. Hence, our current craving for a straight profile and a strong, aggressive mandible is not necessarily the ultimate in attractive facial contours. There are other forms of beauty and we would be in error if we had only one concept of pleasing balance and proportion in the human profile."

We may think of the general term, environment, to encompass everything above and beyond our inheritance. This latter package is most assuredly subject to a multitude of factors which can and which may well alter the morphologic pattern for better or for worse. The school of thought which held malocclusion to be almost wholly of environmental origin has been forced to give way. For example, we no longer read of the childhood diseases and finger sucking as prime movers in the etiology of malocclusion. This is not to say that these and similar environmental experiences are without effect on the developing occlusion, but rather that their effects are largely secondary in nature. It is part of our job to intercept and provide an environmental climate for the dental apparatus which will favor coordinated growth and development in order to realize the full inherited potential of the individual. We can make clinical use of the old adage, "as the twig is bent, so grows the tree." The clinical problem centers about deciding just when to try bending the twig. The obvious answer would appear to be as soon as we are able to decide that the growing structure is headed for trouble. Figure 2 (left) shows the models of a child five years of age presenting with a marked Class II deciduous malocclusion and serious incipient arch length deficiencies. Treatment was declined upon the advice of friends who questioned the need to "straighten baby teeth." Figure 2 (right) shows the models of the same patient at age eleven when he presented again for treatment. Early reduction of the Class II molar relation followed by supervised serial extraction would have prevented the gross malocclusion. Ultimately, our treatment procedure must rise to the occasion, for prevention of malocclusion is our only hope in the face of a rising tide of population and demand for service which

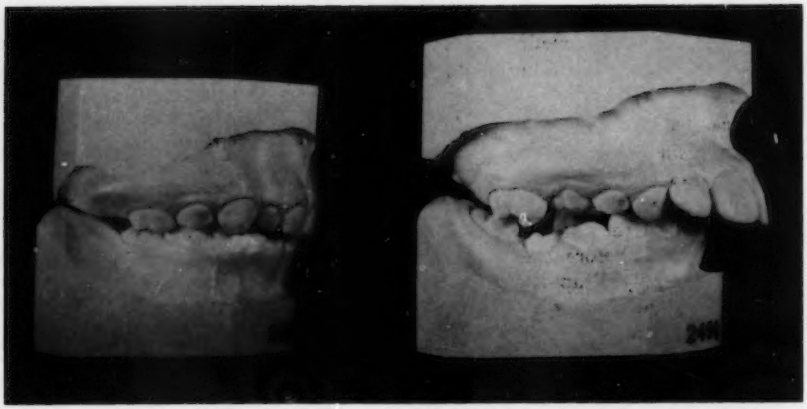

Fig. 2 Left, models of a patient at age five years with a Class II maloeclusion and arch length deficiency. Right, the same patient at age eleven years. Treatment had been declined at the earlier age.

we cannot possibly otherwise meet.

It does not serve us very well to remark simply that growth is the orthodontist's greatest ally. We must try to time our treatment efforts to make maximum use of the phenomenon. It follows that the serious student of orthodontics should also be a student of growth and development. Herein lies the background material to make us truly conscious of the dental apparatus as part of a dynamic biologic system. The appositional nature of bone growth has been demonstrated in conclusive fashion. The nature of mandibular growth in particular is of considerable importance in treatment planning. Like Dewel, I consider the mandibular arch to be the limiting factor, almost without exception, in treatment planning when the possibility of extraction of permanent teeth is in prospect. I place considerable reliance on the oft-repeated work which demonstrates that we cannot expect an increase in intercanine mandibular width of any consequence after the approximate age of six to seven years. By this time, generalized growth of the mandible is said to have al' but ceased, and subsequently we may look to the well-known mandibular growth sites for increase in size of the structure. Stability of intercanine width serves as a useful clinical tool, but like everything else in a biologic system is only approximately true. Likewise, we are all well aware of the fact that some individuals can tolerate orthodontic expansion of the intercanine width. Were this not so, the nonextraction therapies would be wholly unsuccessful in what we judge to be clear-cut extraction cases. However, in the main, persons with normal tone of the oral musculature must be considered candidates for extraction if they lack room for the mandibular teeth within their given arcs. In my estimation, it is wishful thinking to mechanically expand the lower arch to make room for all the teeth during and subsequent to the mixed dentition and expect a stable result. I feel it to be equally futile to place a cuspid to cuspid retainer to establish this new expanded dimension. On the other hand, I do not plan serial extraction for a given case, solely on the basis of measurement, if the arch length de-

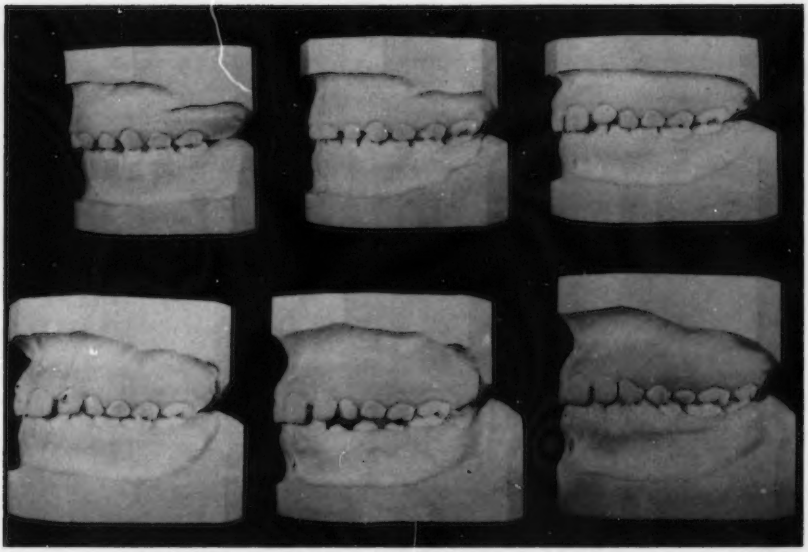

Fig. 3 Serial models of one of untreated identical triplets showing the molar adjustment from the end-on position to the adult cusp and groove relation prior to the loss of the deciduous molars and cuspids.

ficiency is not clear cut. I purposely avoid defining this deficiency in millimeters for myself since such arbitrary rules fail to take into consideration the factors of individual variation. The final decision must rest with the clinician. The clinical ramifications derived from cuspid width stability are several. There would be no point to early extraction of lower deciduous cuspids to make room for the lower four incisors if they are already well up on the ridge in rotated positions, for in so doing we "rob Peter to pay Paul" for space which will not be increased through subsequent intercanine growth. I hasten to add that early bilateral extraction of deciduous cuspids is most certainly indicated where the lower centrals are being forced labially, off the ridge, by the lingually erupting laterals. In so doing, we are setting the stage for serial extraction, but there would appear to be no other choice.

Cessation of generalized mandibular growth has supplied the backdrop for lower arch length calculation as described by Nance[2], Carey[3] and others, in evaluating the available space on the ridge of alveolar bone mesial to the six year molar. The decrease in arch length upon change from the mixed to the permanent dentition is unchallenged. The customary interpretation of physiologic mesial component of force in closing the ranks, so to speak, is open to question. In cases where the first molars have erupted into end-on position, it is commonly supposed that the final adult cusp and groove relation of these teeth is accomplished by differential mesial migration upon the loss of the deciduous molars. The models shown in Figure 3 made in a serial study of identical twin children demonstrate that this is not necessarily the case. One may adjust differentially from end-on position of the first molars

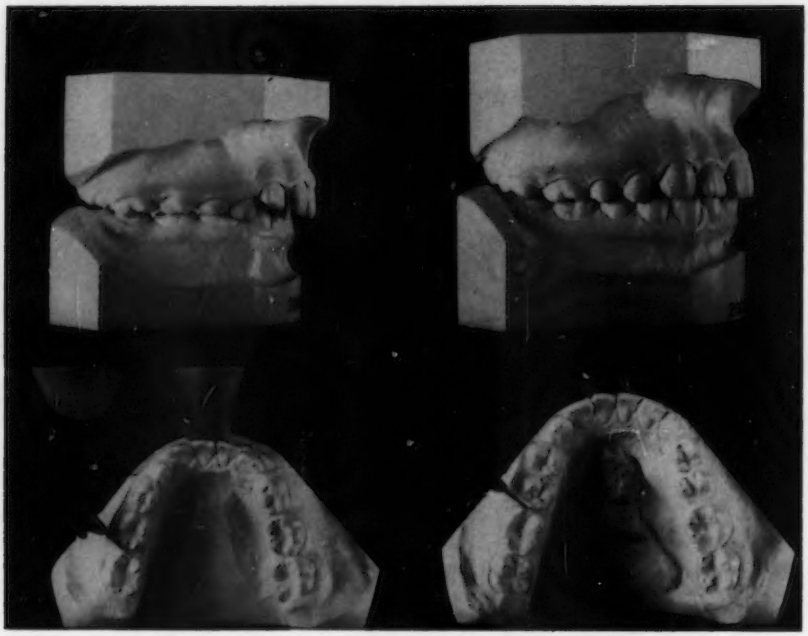

Fig. 4 Beginning and final models for patient, J.C. Note the crowding in the incisal segment prior to treatment. Dividers set at constant length demonstrate maintenance of arch length from the mesial of the first molar to the mesial-incisal edge of the central incisor following the loss of the deciduous teeth.

to the adult cusp and groove relation prior to the loss of the deciduous cuspids and molars. Likewise, there is no physiologic reason why the lower first molar *must* come forward upon loss of the deciduous molars. Regardless of what is said, there is no magic position for this tooth to move on the average of 1.7 millimeters mesially any more than there is a requisite predetermined position for any other tooth. If good cusp and groove relation of the first molars is established and proper holding mechanics maintained, there is no reason why use cannot be made of lower arch space which will otherwise be irreparably lost. Personally, I feel that lingual arches are poor mechanisms for the maintenance of anteroposterior tooth to ridge relation. The long lever arch from the molars to the lingual of the incisors lacks inherent stability and tissue support. On the other hand, they are helpful in the maintenance of arch length at the possible expense of forward migration of the entire mandibular denture in relation to supporting bone. The removable Hawley retainer, although subject to loss and breakage, offers a maximum of retention in terms of total surface application. It has the additional advantage of preventing the extrusion of opposing teeth in cases where premature extractions have been necessary.

Figure 4 shows the models of patient J. C., demonstrating arch length preservation for a full complement of teeth in a case which would otherwise offer no solution short of extraction.

Fig. 5 Beginning and final photographs of patient, J.C.

The patient presented with a Class II malocclusion and a calculated lower arch length deficiency of five mm. The malocclusion was reduced with upper arch banding and occipital traction. Mandibular arch length was stabilized with a removable retainer during the time the deciduous molars were being shed. Bands were then placed on the lower molars, bicuspids and cuspids, and space closure effected by distal movement of the bicuspids. Figure 5 illustrates beginning and final photographs. Before and after tracings (Fig. 6) superimposed on SN and registered on S as are all full tracings in this paper, show the overall facial growth and development over a span of four and one-third years, the Class II relation having been corrected during the first twelve months of this period. The tracings (Fig. 7) superimposed on the lower mandibular border and chin point depict increased vertical alveolar growth with no apparent forward migration of the first molars and incisors upon change from the mixed to the permanent dentition.

I have asked myself in the past, "Might we not set up a better environmental climate for the development of adequate intercanine width in children prior to the cessation of generalized mandibular growth in cases where the clinical prognosis is poor?" It has become increasingly apparent to me that the early closebite is perhaps the greatest single environmental stumbling block in the development of the dentition. We are all aware of the difficulties imposed by closebites in the mixed and permanent dentitions. For the most part, the bragging cases shown at meetings tend to return to the closebite relation when retention is discontinued. One solution is indefinite retention to which some orthodontists subscribe.

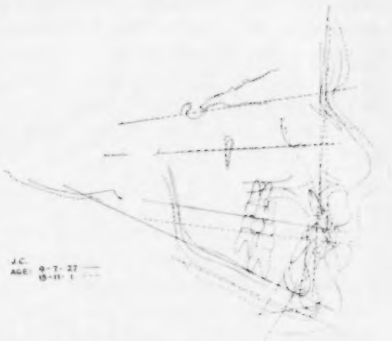

Fig. 6 Tracing of patient J.C. superimposed on the cranial base showing the overall results of treatment and concomitant growth.

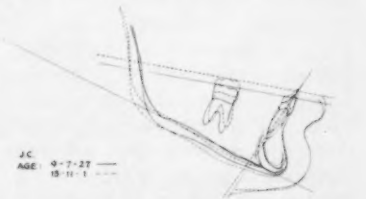

Fig. 7 Tracing of patient J.C. superimposed on the chin point and the lower border of the mandible showing anteroposterior stability of the first molar and incisor.

Until I see evidence to the contrary, I shall continue believing that development of proper overbite relation in closebite cases is best aided by initiation of orthodontic guidance therapy during the deciduous dentition years. For the record, I would like to reiterate my belief that, within the limits imposed by the growth potential, it is possible to modify favorably potential arch length deficiency during the deciduous dentition in cases presenting with favorable anteroposterior tooth relation coupled with deficient vertical relation. By definition, this is the deciduous Class I case with a closebite and potential lower arch length deficiency.[4]

One of the premises upon which I base treatment planning is that intraoral anchorage in the true sense of the word does not exist. I am well aware of the lengthy discussions in this respect to be found in the literature directed to the contrary.[5] I do not mean to say, for example, that I do not use Class II elastics in spite of the fact that they are said to be dirty words in my presence. My point is simple. Anchor teeth, other than ankylosed teeth, don't know enough to stay still when subjected to pressure of sufficient magnitude to disturb their existing equilibrium. Thus, a little Class II rubber mechanics may be a fine thing, but if I pit many teeth against a single tooth, I expect relative stability of the so-called anchorage units and nothing more. If I use push coil springs, pull coil springs, closing loops, or whatever in the mouth, I expect them to be reciprocal in action. As far as I am concerned, anchorage units, whether they be tipped back or upright, disturbed or undisturbed, will move reciprocally. I cannot help but agree with the research findings of Whitman[6] who was quite unable to demonstrate retrabeculation of bone at approximately right angles to the long axes of teeth subjected to orthodontic pressures. This phenomenon, according to the general principles of Wolff's Law, is said to occur as the result of force application to the tooth as Nature's way of setting up a temporary block or barricade to movement. In the final analysis, intraoral anchorage becomes a relative matter and a question of degree in which the orthodontist must decide whether he is willing to pay the price in terms of untoward movement of the tooth or teeth.

It becomes apparent with this rationale that banding of the lower arch in deciduous and in mixed dentition cases would be the exception rather than the rule. Mechanotherapy in the aforementioned age brackets, for the most part, involves the maxillary arch directly and the lower arch indirectly as it is influenced by a bite plane and the tongue. Figure 8 demonstrates the favorable development of the lower arch in a deciduous case in which there was a Class II relation with the maxillary posterior segments in complete buccal relation to the lowers. There was no appliance used on the lower arch. None of the permanent teeth have been banded.

Development of the cephalometer has made possible the analysis of tooth movement which was heretofore quite out of the question. There are no physiologic reasons why normal teeth subject to orthodontic pressures cannot be induced to move in any desired direction. In spite of the fact that the profession has had the cephalometer for a quarter of a century, it is only recently that some researchers have finally admitted that maxillary teeth can be moved bodily toward the distal and that teeth are intruded as well as extruded in certain levelling mechanics.

We are well aware that tooth movement is only possible because of the cellular elements in relation to the connective tissue of the periodontal membrane. Since cellular activity depends

Fig. 8 Models of patient S.B. treated in the deciduous dentition. Fully banded upper arch in conjunction with occipital traction and maxillary bite plane. No appliance used on the lower arch. Increase in mandibular arch width is shown with dividers.

on the availability of local blood supply, it follows that extrusion is the easiest movement, followed by tipping, rotation, bodily movement and intrusion, in order of increasing difficulty. Clinical movement of teeth is accomplished in spite of force applications which show little or no understanding and regard for the integrity of the supporting tissues. This is true, thanks to repair, which is again the product of cellular activity and concomitant blood supply, in the undermining and removal of necrotic tissues which resulted from the initial orthodontic insult. Excessive force application has been characterized in some quarters by such terminology as "vigorous" and "positive." This is supposed to accomplish all manner of things ranging from faster completion of the case to stimulation of the growth of bone. At a meeting in 1958 Dr. Alton Moore reported the results of a statistical comparison between a series of Dr. Charles Tweed's cases and a comparable series of treated cases in which Tweed mechanics were not employed. He was unable to demonstrate the oft discussed stimulation of mandibular growth supposedly resulting from Dr. Tweed's mechanics. I still find myself in the same position that I held some four years ago in a paper before the P. C. S. O. in Seattle, at which time I stated in part . . . "the burden of proof for stimulation of bone growth by orthodontic mechanics (other than that normally expressed in vertical alveolar dimension) rests with those making the claim." Generalized stimulation of bone growth has been demonstrated in man following the injection of growth hormone in children. To the best of my knowledge, no one has yet succeeded in demonstrating differential stimulation of bone growth in man, i. e., inducing a single growth site to activity while other sites remain quiescent. As a matter of fact, we do not understand the genetic mechanism underlying differential growth rates and amounts in any organism.

It is beyond the scope of this paper to deal with the details of force appli-

cation in tooth movement. However, among the more recent works are the papers by Reitan[7] and Storey and Smith.[8] These papers point up once again that force application should be within the realm of physiologic reality. Every operator likes to think he treats the tissues with due respect, but few have any real idea of the forces being used clinically in terms of grams per square centimeter of root surface involved. Doctor Frederick Noyes once made a statement to the orthodontic profession which should be more widely known and appreciated. "It is very difficult for the orthodontist to understand that force does not move teeth, but rather should be only of sufficient magnitude to stimulate the production of cellular elements which are responsible for tooth movement." Exacting control of maximum numbers of teeth in an arch is possible to a greater degree with the edgewise appliance than with any other. Forces of four or five hundred grams are easily applied to a single tooth. This is easily demonstrated, for example, in the ordinary activation of a vertical loop in a rectangular sectional arch. In my estimation, the best clinical yardstick in deciding force application was laid down by Oppenheim. He warned against soreness of teeth, looseness of teeth, and blanching of the soft tissues upon adjustment of the mechanism. I think that we can agree that orthodontic movement of teeth should be an almost painless affair. I do not use the customary .016 initial round levelling wire in a fully banded arch as I was taught in school. Smaller sizes, ranging from .012 to .014 will accomplish the same thing in what appears to me to be less time (if that be so important) and with much less discomfort to the patient. It might be in order to comment on the relatively new levelling arch wire consisting of a bundle of four .010 round steel wires. This wire obviously has greater resiliency than a single wire of comparable cross section. However, the operator should not be deluded into thinking that such an arch wire exerts less force and is therefore more gentle than, for example, a .016 wire. Table I shows the results of a simple typodont setup in which a series of archwires were subjected to a 1.0 mm deflection over an 18 mm span. This represented the midpoint between the typodont first molar and the first bicuspid. Accordingly, the scales measured the force in grams which would have been exerted on the second bicuspid and reciprocally on the first bicuspid and first molar. There was a measured force of 100 grams with the .012 round steel arch; 400 grams with the .016 arch; 475 grams with the bundle arch (four .010 wires); and about 1900 grams with the .021 x .025 arch. In this crude experiment, even the very lightest archwire exerted a force beyond physiologic limits. We should not excuse ourselves in excessive force application merely because we seem to get away with it. Rather, I think, we should try to do something about it.

Table I

COMPARATIVE TENSIONS EXERTED BY ARCHWIRES UPON ONE MILLIMETER DEFLECTION OVER AN EIGHTEEN MILLIMETER SPAN
(stainless steel)

.012 rd.	100 gms. (3½ oz.)
.016 rd.	400 gms. (14 oz.)
Quadruple .010 rd.	475 gms. (16 oz.)
.021 x .025	1900 gms. (4 lbs.)

Analysis of tooth movement with cephalometric films is not as simple as some would have us believe. The great difficulty lies in deciding the method of superimposition of the second tracing since the variables of mechanical error

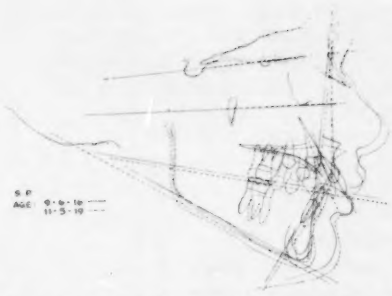

Fig. 9 Patient S.P. treated in the mixed dentition with occipital traction against a fully banded upper arch. No appliance used in the lower arch. Note the distal movement of the unerupted cuspid and bicuspid during treatment. Bodily movement of the first molar is quite evident.

and structural growth have intervened. It is possible to arrive at various answers depending upon how the second registration is made. This point is especially well made by Krogman and Sassouni[9] in a comparative study of various methods of cephalometric analysis applied to a single case. We need more information regarding the location of surface deposition of new bone in the growing facial structure. The work of Bjork[10] using small metal implants in the facial skeleton of children to provide reference points for superimposition of tracings may well alter certain of our current methodology in this respect.

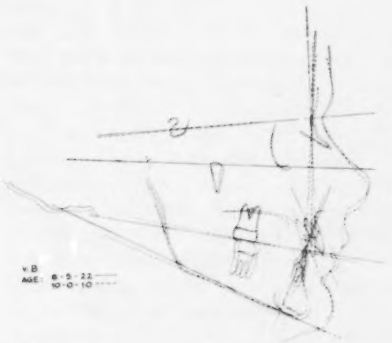

Fig. 10 Cephalometric tracings for patient V.B. demonstrating the correction of a Class II malocclusion by full maxillary arch banding and occipital traction. Molar correction in this case was effected by mandibular growth. Lingual bodily movement of the maxillary incisors is clearly shown.

Tooth movement is accomplished with considerable rapidity in certain cases before appreciable growth has intervened. Analysis of tooth movement is easy in these cases and is more so in adult cases where facial growth is no longer a variable. Figure 9 shows the cephalometric tracings for patient, S. P., in which the distal bodily movement of maxillary molars and incisors through the medium of occipital traction is demonstrated in conclusive fashion. This should not be construed to mean that this is the one and only way in which Class II malocclusion is reduced in my hands, for most certainly some cases are corrected as the result of tooth movement, jaw movement and resultant growth direction of the facial complex. Figure 10 illustrates the cephalometric tracings for patient V. B. in which a Class II malocclusion was treated with full maxillary arch banding and occipital traction. No appliance was used in the lower arch. The tracings superimposed on SN and registered on S depict an elapsed time of approximately ninteen months. Molar correction in this case was effected by marked forward growth of the mandible. However, lingual bodily movement of the flared maxillary incisors is quite evident.

Figure 11 of patient B. S. shows the tracings of a Class II case in which full banding of the maxillary dentition and occipital traction was employed over a period of ten months. The tracings, superimposed on SN and registered on S, show essentially no growth of the anterior cranial base while growth of

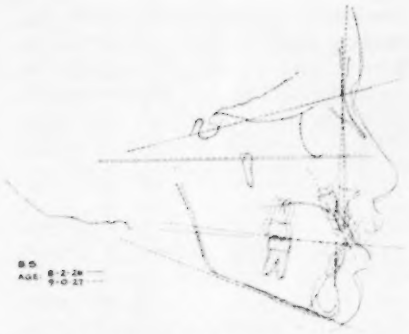

Fig. 11 Tracings of patient B.S. showing correction of a Class II malocclusion by posterior movement of the maxillary denture. Growth of the facial skeleton has been negligible during the treatment period of ten months.

the facial skeleton has been negligible over this short period of time. Correction of the malocclusion in this case was obtained almost wholly by distal movement of the maxillary teeth. Forward growth of the mandible has played a minor role in this case.

Figure 12 presents the tracings for patient S. G. demonstrating again the reduction of a Class II malocclusion with occipital traction against a fully banded upper arch. No appliance was used in the lower arch. The tracings are superimposed on SN and registered on S. The maxillary incisor has been retracted bodily while the first molar is in the same anteroposterior position. Molar correction in this case was gained by marked downward and forward mandibular growth.

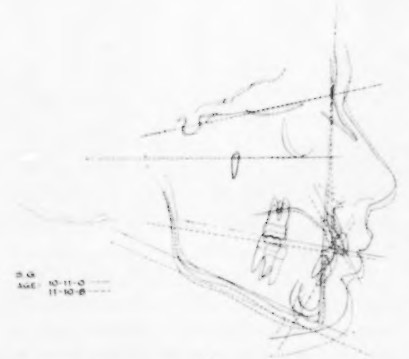

Fig. 12 Tracings of patient S.G. in which correction of the Class II relation was obtained by marked downward and forward mandibular growth. Lingual bodily movement of the maxillary incisors is seen.

It has been said that movement of deciduous teeth does not affect the permanent tooth buds underlying them.[11] The work of Breitner[12] on the orthodontic movement of the deciduous dentition in monkeys some nineteen years ago suggested quite the contrary. It would be most difficult to imagine how the tooth germ of an unerupted bicuspid, for example, forming and nestled between the roots of the deciduous molar could not be influenced by movement of the overlying tooth. Likewise, the unerupted maxillary cuspids and incisors should come under the restrictive influence of the oral musculature as the posterior teeth are taken distally. I assiduously avoid distal tipping of deciduous molars for the very reason that in so doing there will be a varying mesial root tipping and unfavorable mesial movement of the permanent tooth bud with it. Reference to the tracings in Figure 9 shows the favorable distal movement of the maxillary bicuspids and cuspids during mixed dentition treatment, the deciduous molars having been shed subsequent to band removal. The clinical results of carrying the deciduous molars and first molars distally in bodily fashion with little or no tipping has been most gratifying.

Words of warning have been sounded regarding root resorption and root-end deflection if the maxillary incisors are banded prior to the near completion of root closure. From a purely me-

chanical point of view, it would seem likely that a comparatively delicate structure such as Hertwig's sheath would be deflected when subjected to pressure. Similarly, it is not too difficult to find maxillary laterals with curved root tips although this is seldom seen in central incisors. The partially formed root-end possesses a comparatively great blood supply which, in turn, provides the cellular elements requisite to bone removal upon the initiation of tooth movement. I have yet to see a case in which I felt there was root damage as the result of tooth movement prior to root closure. I realize this point can be argued since one can only estimate the probable root length from the outline of the partially formed structure. One finds varying degrees of root resorption following tooth movement in older children and it is almost axiomatic to say that we may count on root resorption of maxillary incisors in adult treatment.

The typical mixed dentition treatment of a Class II malocclusion presenting with a clinically good lower arch will require banding of all available maxillary teeth. Obviously, this will vary, depending on the age and teeth present in the maxillary arch. My basic objective in all so-called early treatment is correct interdigitation of posterior teeth with the concomitant maintenance of a flat occlusal plane in the maxillary arch. The rationale for a flat occlusal plane in the upper arch will be considered later. It will not matter to me whether or not the patient has adequate or insufficient mandibular arch length to accommodate the permanent dentition. The primary aim is the same in both instances, namely, establishment of normal cusp and groove interdigitation of the posterior teeth, thereby setting the stage for correct anteroposterior relation of the succeeding molars and bicuspids. This invariably means extraoral traction against the maxillary teeth and strict avoidance of mesial forces bearing against the mandibular arch.

Those employing the ribbon arch mechanism must treat the deciduous dentition prior to the near exfoliation of the deciduous maxillary incisors and must postpone early mixed dentition treatment until the maxillary incisors have erupted. If one believes that the unerupted maxillary incisors and the supporting premaxillary base are not influenced by distal movement of the deciduous cuspids and posterior teeth, there is good clinical reason for avoiding treatment during the five to seven and one-half year age range. However, one must admit that these are favorable years for treatment if the use of extraoral traction is in prospect. Clinically, I find it quite feasible and realistic to undertake treatment during this age period with the edgewise mechanism. The maxillary deciduous cuspids and all available teeth posterior to them are banded. Occipital traction is used against the cuspids by means of free-sliding headcap hooks which carry the deciduous cuspids and posterior teeth into normal relation along the archwire much like sliding beads on a string. Obviously, every effort is made to avoid distal tipping in order to encourage mass bodily movement. The rectangular archwire rests in proximity to the anterior alveolar process but does not bear on it directly. The process and unerupted incisors are encouraged to retreat, as it were, as the lip exerts its restricting influence. Self-correction in this area is more marked if reduction of the Class II relation is undertaken while the permanent incisors are completely unerupted and if lip control has not been lost by extreme protrusion of the supporting bony process. By the same token, there is every reason to wait for complete eruption of the two

centrals before banding if these two teeth have already started to erupt when the patient presents. When the centrals are incorporated into the arch system, headcap hooks are soldered to the archwire and mass movement of the entire maxillary denture is undertaken. It is of prime importance to preserve arch length with stops mesial to the molar tubes to prevent differential movement of the centrals into the eruptive path of laterals or permanent cuspids as the case may be. In cases where the permanent centrals are part of the arch system and the laterals lack room for eruption, I use sliding hooks against the deciduous cuspids, carrying them and the posterior teeth back until space is created for the laterals. Thereupon, the headcap hooks are soldered to the archwire and arch length is preserved by molar stops.

For those using the edgewise mechanism who have never undertaken mass movement of the maxillary denture with occipital traction, it is in order to mention a few details with respect to management of the archwire. I invariably use an .021 x .025 steel archwire with headcap hooks in the cuspid-lateral interspaces. As mentioned before, these hooks may be soldered to the archwire or free sliding as indicated. Active labial crown torque is incorporated in the incisor area of the archwire irrespective of the existing inclination of these teeth. The posterior segments are torqued slightly to the lingual in order to counteract the tendency for the molars to tip buccally. The cuspid areas of the archwire are kept flat, maintaining the desired intercuspid width and labiolingual inclination. I attempt to maintain the arch in a flat plane at all times, dictated in part by the band levels on the teeth. As traction is brought to bear on the arch, there is a tendency for the maxillary incisors to develop spacing and tip lingually as the buccal segments tend to tip buccally and expand. These untoward actions must be checked and compensating bends in the archwire reinforced each time it is removed. In addition, I find it advisable to incorporate slight mesial bends for the laterals so that upon completion of treatment, these teeth will have a slight mesial crown inclination. I generally figure-eight the four incisors as an added precaution. I consider it an error to gather the spaces between upper incisors at the beginning of treatment by tying back a round wire. In so doing, there is a varied degree of undesirable forward motion of the incisor apices. Correspondingly, it is difficult to correct the axial inclination of incisors toward the close of treatment if they have been tipped lingually previously. On the other hand, by careful maintenance of incisal axial inclination during treatment, one may finish the final closure of anterior space with a small round arch without detriment to incisor esthetics.

Many different designs of occipital headgears have been concocted in an effort to make them more presentable. I still use the familiar Johnson[13] headgear made of rug binding. They are probably the worst looking of the lot and are real headshrinkers if they are laundered. Nevertheless, they have the virtue of staying in place and permit unilateral traction if it is indicated. Likewise, I still use the Terwilliger hooks which permit directional tension adjustment. Theoretically, the patient returns the hooks for sterilization and re-use.

I would like to take time at this juncture to point out what I consider to be objections to the so-called Kloehn approach to Class II treatment which conventionally involves banding upper first molars and directing the maxillary denture distally by cervical traction delivered directly to the molars by means

of a removable face bow. In essence, the banding of first molars and use of cervical traction on these teeth makes use of the fact that the dental arch is bound together, so to speak, by a connective tissue band of transseptal fibers. This, coupled with favorable restrictive influence from the oral musculature makes possible the reduction of the malocclusion. Integrity of the transseptal tissue is lost whenever space is opened mesial to the banded molars. The patient is asked to wear extraoral traction but the incisor teeth are not being controlled axially. The resultant cervical force being applied to the molars is somewhere below the level of the maxillary occlusal plane while the level of the occlusal plane, itself, is not under control. Cervical gear, on the average, rests at the level of the third cervical vertebra. Since the occlusal plane is almost invariably above the level of the neck gear, and since no one has repealed the law about pulling one's self up by his boot straps, the resultant force must lie somewhere in between. I have no quarrel with those using this approach to treatment. Rather, I feel it preferable to control as many teeth as possible, especially when the patient is forced to wear extraoral traction.

I have had the privilege during the past year to see some spectacular clinical examples of treatment of Class II, Division I malocclusion using a modified Kloehn-type appliance. The headfilms showed interesting downward tipping changes in the posterior palatal area accompanying treatment. This minimal appliance therapy may well be indicated in selected Class II, Division I cases with the maxillary incisor apices well back under supporting bone and with relatively flat maxillary occlusal planes. The significance of the palatal changes must await future assessment. Minimization of angular changes in the occlusal plane may be significant when one remembers the considerable research indicating the instability of this type of dislocation. It is not my purpose to deprecate cervical traction, per se, for I use it routinely in both Class I and Class II cases against a fully banded upper arch in openbite cases where controlled downward and backward movement of the maxillary incisors is indicated.

The bulk of Class II malocclusion is characterized by a closebite. In reduction of the malocclusion, one is faced with this and the related problem of vertical dimension. A fully banded maxillary denture which has been levelled by various archwires, with the posterior teeth in upright position and the marginal ridges in good relation, sets the stage for bite opening which is simple and effective. In these so-called upper arch headgear cases, a flat maxillary bite plane placed upon band removal is generally successful in effecting bite opening through differential eruption of the lower posterior teeth. This is easily demonstrated by headfilms in which the mandibular incisors are seen to maintain their existing vertical height while the posterior teeth erupt into occlusion. However, the time lapse is sufficient in some cases that the corrected molar interdigitation is lost before the posterior teeth are again in occlusion with the plane in place. I began using a flat maxillary bite plane in conjunction with upper headgear treatment at least three years ago as the result of failure of certain Class II cases to maintain the corrected anteroposterior tooth relation following band removal while waiting for the lower posterior teeth to erupt into occlusion. I have been asked repeatedly if distal en masse movement of maxillary teeth is not prevented by the bite plane in situ. Actually, teeth are not prevented from moving

distally with palatal coverage in place any more than they are prevented from moving mesially when Class III force is applied against the upper arch with palatal coverage in place. Were this not so, there would be no need to "back up" the upper arch in cases where anchorage is being set up in the lower arch. However, I generally do not use the bite plane in these upper arch headcap cases until the posterior teeth are about in edge to edge relation. The case looks worse when the bite plane is inserted since the jaw is opened a few millimeters and chin point is down and back of its previous position. I continue the headcap to the upper denture until the desired vertical and anteroposterior relation is achieved. Retention, upon band removal, becomes a matter of maintenance of the established tooth and jaw relation. I find myself with a variable degree of success in the maintenance of the desired vertical relation when the case is out of retention not only in the mixed dentition but in the permanent as well.

In over one hundred Class II cases treated with occipital traction in the mixed and deciduous dentition, I have never impacted an upper molar. I cannot help but attribute this, in part, to plain good fortune but also to the fact that distal tipping of molars is minimized during treatment. Therefore, I do not have to count on their spontaneous uprighting following treatment. However, I have seen second molars erupt in buccal version more than once as the probable result of Class II headcap mechanics. Fortunately, these second molars can be guided into correct buccolingual alignment with clasp wires extending from the retainer. Similarly, I have never cut off the root of a maxillary lateral during the reduction of Class II malocclusion. This, I believe, is due to the maintenance of arch length coupled with the fact that the high, unerupted cuspid is favorably influenced in its eruptive path. Clinically, the cuspids erupt later into good anteroposterior relation. In treated cases possessing extreme protrusion, the newly erupted cuspid may require distal tipping with a suitable retainer clasp wire. Additional banding treatment is needed on occasion.

In June 1950, about a year after graduation from dental school I first began upper headcap treatment of Class II malocclusion, on a limited basis, in mixed dentitions with clinically good lower arches. Teaching at that time held that both arches must be banded in order to maintain coordination or synchronization.

Seventy-three of my completed upper arch headgear cases had sufficiently completed records to warrant analysis. Bands were worn in these cases for a calculated mean of thirteen months. However, the treatment time ranged from three to thirty months. Obviously, this extreme range reflected patient level of cooperation as well as the difficulty of the case. I am assuming that my orthodontic competence was more or less constant, irrespective of what the level may have been. Forty-two of the seventy-three completed cases were selected on the basis of above average cooperation with respect to headcap wear. In collecting the new sample, a conscious effort was made to disregard total treatment time for any given case. The forty-two cases required a total of 473 months of treatment for an arithmetic mean or average of 11.3 months per case. Treatment time ranged from three to twenty-one months in this new sample. Even without detailed analysis it becomes evident that the average may not have a great deal of significance. For this reason, the mode, or most common treatment time might be of value. Accordingly, treatment times were grouped as shown in Table II. It is im-

Table II

DISTRIBUTION OF TREATMENT TIME FOR 42 LATE DECIDUOUS AND EARLY MIXED DENTITIONS

No. Cases	Months	No. Cases	Months
1	3	3	12
1	4	1	13
1	5	1	14
2	6	0	15
5	7	1	16
5	8	4	17
3	9	3	18
3	10	1	19
4	11	2	20
		1	21

Average treatment time = 11.3 mo.

mediately apparent that neither the mode nor the mean is of significance in terms of the projected treatment time for any given single individual. The many uncontrolled variables dictate the random distribution of treatment months. I see no harm in telling one's self that the average treatment time is 11.3 months as long as one doesn't take it to heart. It is unrealistic to apply the average value to the single individual here or elsewhere in treatment planning or analysis.

Retreatment was necessary in four of the forty-two cases due to loss of the corrective buccal relation. Two of the four cases were identical twins who were treated in identical fashion and collapsed the same way. These children had very flat occlusal anatomy in the first molars which I suspect was responsible for the failure of the teeth to lock in good relation. Retreatment was successful at the time the bicuspids were erupting. I have no explanation for the return to Class II in the third case. The fourth case returned to Class II molar relation on one side only. Both of these latter cases have been retreated without incident and are out of retention.

I do not want to give the impression that my mixed dentition cases require additional treatment at the level of four out of forty-two or roughly eight per cent. Actually, a great many of my mixed dentition cases require subsequent treatment but not because of failure in my primary treatment objective. This, it will be recalled, is the establishment of normal molar relation. Corrected vertical relation will have been obtained with the bite plane. If the patient has a clinically good lower arch and no dental anomalies, I expect the reduction of Class II malocclusion to be a one shot affair. Actually, the parents are told in writing that additional banding treatment may or may not be indicated, irrespective of my personal feelings in any given case to the contrary.

Potential four bicuspid extraction cases presenting with a Class II malocclusion are treated early in order to establish correct anteroposterior relation of the buccal teeth at a time when the child is most amenable to extraoral traction therapy. Serial extraction of deciduous and permanent teeth is initiated and carried on from this point. The patient wears a flat maxillary bite plane intermittently during the intervening years until secondary full banding treatment is indicated. The bite plane is a valuable adjunct to maintain vertical dimension, prevent serious distal tipping of the lower incisor segment and helpful in guiding the teeth into good interdigitation. Secondary banding treatment then becomes a relatively simple matter of tooth alignment and completion of space closure. The need for extraoral traction at this stage is minimized or eliminated.

The treatment findings in the present series of cases are quite different from those reported in 1954 by Graber[14] in a more or less comparable group of one hundred patients. The shortcom-

ings reported in his mixed dentition treatment results made no mention of the mechanical deficiencies in his appliance therapy. With only two molar teeth banded and cervical traction employed, he pointed out the following:

1. Lack of control of axial inclination of incisors.
2. A low level of success in distal bodily movement of molars.
3. Poor success in control of vertical dimension.
4. Temporary impaction of upper molars in some cases.
5. Successes associated mainly with pubertal growth spurts.

I go out of my way to mention the shortcomings of the method that Graber was using at that time because, in the first place, I have had no serious difficulties in these areas. But secondly, and more important, Graber's treatment difficulties were directly assignable to appliance inadequacies, a fact which he apparently failed to recognize and report. In generalizing, one must be quite certain that it is being done from a broad base and not from a limited point of view; in this case, an appliance incapable of doing the things being asked of it. The basic idea of retracting the protrusive maxillary denture is every bit as good as it was when Angle reported it in 1887.

Summary

This paper has been an attempt to describe my methods in handling malocclusion in the deciduous and early mixed dentition. There are no world-shaking conclusions to be drawn. The underlying theme is prevention, for malocclusion can only become worse and more difficult if left untreated until later years. One may disagree entirely with the various rationales which underlie the treatment procedures described. I have been in research long enough to have learned that there must be error on both sides where more than one school of thought exists regarding a given problem. Time will be the final judge.

The Medical Center

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An Investigation Of The Vertical Overbite During The Eruption Of The Permanent Dentition

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The general process of the development of occlusion has received considerable attention dating back to our earliest recorded dental knowledge. Some aspects of occlusal development have been investigated in detail, but the problem of the vertical overbite is relatively less studied. In order to increase our understanding of this subject, the following study of the vertical overbite was designed.

REVIEW OF THE LITERATURE

The vertical overbite has been defined by Strang[1] as, "the overlapping of the upper incisors over the lowers in a vertical plane."

To-day, we consider a moderate degree of overbite to be a normal characteristic. Neff[2] expressed overbite as a percentage of the lower incisor covered by the corresponding upper incisor. Further, he considered a twenty per cent overbite as ideal.

On the other hand, an excessive degree of overbite has been said to contribute to the etiology of a variety of conditions affecting the masticatory apparatus. These conditions include relapse following orthodontic treatment[3], interference with the normal closure pattern of the mandible[4], periodontal disease[5] and malfunction of the temporomandibular joint[6].

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, Horace H. Rackham School of Graduate Studies, University of Michigan, 1960.

With regard to the factors influencing the extent of the overbite itself, an infinite variety of clinical opinions and research findings have been reported in the literature. Among the most important factors are:

1. *Cusp Height.*

It has been stated by Bonwell[7] in connection with his work on artificial teeth, "that the overbite in the incisor region is governed by the depths of the cusps of the molars and premolars, which vary in different individuals." This was corroborated by Popovich[8], who, studying the natural dentition, found a strong positive correlation existing between cusp height and the degree of the vertical overbite in cases of normal occlusion.

2. *Ramus Length.*

Diamond[9] wrote, "the primary factor in increasing the vertical development of dental height is the growth in length of the ramus." He indicated that retardation of ramus length growth inhibited the eruption of the posterior teeth but did not interfere with the eruption of the anterior teeth, thus resulting in an excessive degree of overbite. In testing this hypothesis, Wylie[10] compared the ramus length in cases of slight (1.5 - 2.0 mm) overbite with that found in cases of severe overbite, and failed to find any significant difference between the two. Later, Popovich[8] found that there was a significant negative correlation between ramus length and overbite in his group of Class

II deep overbite cases but this relationship was not found in the Class I group.

3. *Molar Height.*

This term has been used to indicate the degree of eruption of the posterior teeth. Following Diamond's reasoning, one might expect to find a difference in molar height between normal and severe overbite groups. Indeed, this was Wylie's[10] finding. Prakash and Margolis[11] found a strong negative correlation between lower molar height and the depth of the overbite, while Popovich[8] found such a relationship existing for the upper molar height in Class II cases only. He found no correlation whatsoever between lower molar height and the degree of the overbite.

4. *The Interincisal Angle.*

The relationship of this factor to the degree of the overbite was described by Steadman[12], who reported that the degree of the overbite was dependent upon the degree of angulation of the incisor teeth. It was shown that the overbite decreased as the interincisal angle decreased below 180 degrees, and increased at an even more rapid rate as this angle exceeded 180 degrees. Popovich[8] confirmed this finding by showing that significant positive correlations exist between the interincisal angle and the degree of the vertical overbite in deep overbite cases (Angle Classes I and II). In Popovich's[8] Class I cases with a normal degree of overbite, this relationship was not evident.

5. *Incisor Dimensions.*

Neff[2] has reported that the degree of overbite is related to the harmony, or lack of it, existing between the mesiodistal dimensions of the upper and lower incisor teeth. Neither Bauerle[13] nor Bolton[14] was able to confirm this observation using Neff's "anterior coefficient," and both agreed that a "significant correlation could not be found when the degree of overbite was related to tooth size, via the anterior ratio."

Studies of a longitudinal nature on the subject of the vertical overbite have been infrequent. One such study employing serial record casts was carried out by Barrow and White[15] who reported that the mean overbite decreased slightly between the ages of four and five years, increased by 1.75 mm. by eleven years, and remained relatively unchanged thereafter. After examining lateral cephalometric films of a group of Swedish boys observed at twelve years and again at twenty years, Bjork[16,17] reported an average reduction in the vertical overbite of 0.65 mm. during the period twelve to twenty years. More recently, in a study carried out on serial record casts, Bauerle[13] states, "it will be seen that, typically, the overbite increases from 1.75 mm. at the deciduous age, reaches a maximum of 3.8 mm. at age twelve, and then decreases to 3.4 mm. at age fifteen." Bauerle[13] found no significant sex differences at any age, no significant correlation between the degree of overbite in the late deciduous dentition and that at age fourteen and one-half, and no relationship between the overbite at age nine and that at age fourteen and one-half. These findings would appear to be in contradiction to the statement by Barrow and White[15] that the overbite remains relatively stable after eleven years, since Bauerle[13] found the reduction between twelve and fifteen years to be significant.

Method and Material

This study consists of two parts: 1) the study of record casts and 2) the study of lateral cephalometric films.

Long series record casts from the University of Michigan Elementary and High Schools Growth Study were select-

ed. These casts covered the age period from nine to sixteen years inclusive. the impressions being taken as nearly as possible to the subject's birthdate. The casts were selected according to the following criteria:

1. All subjects must show contact between upper and lower incisor teeth.

2. Only subjects having Class I (Angle) molar relationship were considered.

3. All subjects must be orthodontically untreated.

4. There must be no congenitally missing teeth, nor space loss due to caries.

5. There must be no severe rotations.

6. There must be no spacing nor crowding estimated to be greater than two mm in each arch.

In order to increase the sample size, additional casts were examined on a cross-sectional basis and the data added to the serial material. In addition, the data compiled by Bauerle[13] were tested against the data from the present study and, since there was found to be no statistically significant difference between the two samples at any age, the data were combined.

Before measurement, the casts were examined and all the artifacts which might interfere with the occlusion removed. They were then oriented in centric occlusion (See Fig. 1). A plane of occlusion was estimated by sighting a line from the tip of the maxillary central incisor to the tip of the mesiobuccal cusp of the first permanent molar of the same quadrant. A fine pencil mark, in line with the plane of occlusion, was then scribed on the labial surface of the lower central incisor. The distance from this point to the incisal edge of the lower central incisor was then measured to the nearest tenth of a millimeter using a fine pointed vernier caliper. This measurement was

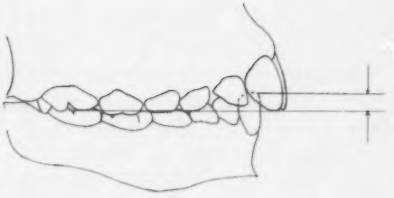


Fig. 1

then recorded as the overbite for the individual at the appropriate age.

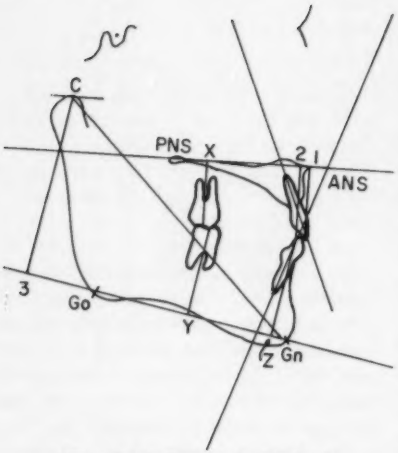
From these measurements, means were computed for both sexes at all ages, nine through sixteen years, and tests of significance ('t' tests) were carried out in order to compare the two sexes. Lateral cephalometric films of the same individuals included in Bauerle's[13] cast study were obtained. To these data were added a group of similar films from the files of the University of Michigan Elementary and High Schools Growth Study. All cephalograms were taken with the teeth in occlusion, approximating the birthdate of the individual. All subjects included in this part of the study were required to meet the same criteria used in the selection of the record cast.

Tracings were made of these films and measurements were made from the tracings using a fine pointed vernier caliper. The following points of reference (See Fig. 2) were used:

1. Anterior nasal spine, ANS.

2. Posterior nasal spine, PNS.

3. ANS - PNS plane. This plane was chosen as the basic plane of reference for the majority of the measurements. Since it has been shown by Brodie[18] that this plane "descends from the cranial base in such a manner that its successive stages are parallel to one another," and since this plane is situated in close proximity to the area being studied, it is well suited to the purpose of this study.



The Cephalometric Method.

Fig. 2

4. Crown tip of the maxillary central incisor, $\underline{1}$.

5. Crown tip of the mandibular central incisor, $\overline{1}$.

6. Midpoint of the occlusal surface of the upper first permanent molar, $\underline{6}$.

7. Midpoint of the occlusal surface of the lower first permanent molar, $\overline{6}$.

8. Mandibular plane (Go - Gn).

9. Condylion, C.

Using these points of reference, the following measurements were made (Fig. 2):

1. Anterior alveolar height (upper), the length of a perpendicular erected from the ANS - PNS plane to the crown tip of the maxillary central incisor, $(1 - \underline{1})$.

2. The length of a perpendicular erected from the ANS - PNS plane to the crown tip of the lower central incisor, $(2 - \overline{1})$.

Having these two measurements, the extent of the overbite for this age can now be calculated by subtracting the latter measurement from the former.

3. Ramus length, the length of a perpendicular erected from the mandibular plane to condylion, (C - 3).

4. Anterior alveolar height (lower), the length of a perpendicular from the mandibular plane to the crown tip of the lower central incisor, $(Z - \overline{1})$.

5. The angle of the upper central incisor to the ANS - PNS plane.

6. The angle of the lower central incisor to the mandibular plane.

7. The interincisal angle.

8. Posterior alveolar height (upper), the length of a perpendicular erected from the ANS - PNS plane to the midpoint of the occlusal surface of the upper first permanent molar, $(X - \underline{6})$.

9. Posterior alveolar height (lower), the length of a perpendicular erected from the mandibular plane to the midpoint of the occlusal surface of the mandibular first permanent molar, $(Y - \overline{6})$.

10. Mandibular length, (C - Gn).

After tabulating the values for the eleven variables including overbite at all ages, nine to seventeen inclusive, the data were prepared for processing on the I. B. M. 704 Computor. Means, standard deviations and correlations for various groups and combinations of groups were thus obtained. Statistical procedures applied to the material produced by the computor consisted of Z score transformations to test the significance of the correlations, and 't' tests to check for significant differences between the means of the various measurements.

Findings

1. *The study of record casts.*

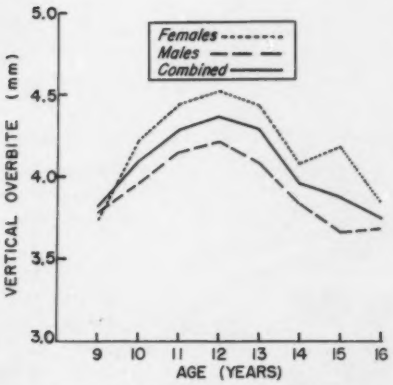
A. *Variation in the vertical overbite with age.*

Table 1
The Vertical Overbite Age 9-16 Years

Age	Mean(mm)	S.D	Range	N
9	3.81	1.063	1.2-5.6	58
10	4.10	0.992	1.3-6.5	79
11	4.29	0.977	1.7-7.2	78
12	4.37	0.876	2.2-7.2	74
13	4.29	0.907	2.3-7.5	69
14	3.97	1.018	2.3-7.8	65
15	3.88	0.947	1.9-7.3	54
16	3.75	1.149	1.9-7.3	48

Table 1 illustrates the extent of the vertical overbite for each age, nine through sixteen years. Testing revealed no statistically significant difference between males and females at any of these ages, therefore, the combined data are listed.

From these data it will be seen that the mean overbite for the sample increases in extent from 3.81 mm at age nine years to reach a maximum of 4.37 mm at age twelve years. Following this, there is a gradual decrease to 3.75 mm at age sixteen. Tests of significance indicate the 0.56 mm increase between the ages nine and twelve years and the 0.62 mm decrease between twelve and sixteen years to be highly significant (P=.001). These findings therefore substantiate those reported by Bauerle[13].



Variation in the vertical overbite (Cast Study).

Fig. 3

Figure 3 is a graphic presentation of the data in Table 1. It can be seen that the greatest incremental increase in the overbite (0.29) mm) occurs between the ages of nine and ten years, and the greatest decrease (0.32 mm) between the ages of thirteen and fourteen years. Although the difference between the mean overbite of males and females is not statistically significant, the mean for females tends to be greater than that for males except at age nine. The mean time at which the peak of the overbite occurs is the same in both sexes.

B. *Individual Variation.*

Although Figure 3 is representative of the sample as a whole, a considerable degree of individual variation is noted within the group. This individual variation is indicated by the wide range of the overbite measurement at all ages. The standard deviation being near 1.0 mm at each age indicates little change in variability with age.

The variability amongst individuals was evidenced by the range and standard deviation at each age. Further, although the great majority of individuals in the serial data showed curves similar to that illustrated in Figure 3, others showed either increase to a peak and no reduction, or a steady increase throughout the length of the observations, while a few exhibited no definite pattern. Of those individuals who followed the typical pattern, there was considerable variation with respect to the age at which the peak of the overbite was reached (ten - fourteen years). This agrees with Bauerle's findings.

II. *The Study of Lateral Cephalometric Films.*

A. *Variation in the vertical overbite with age.*

Table II

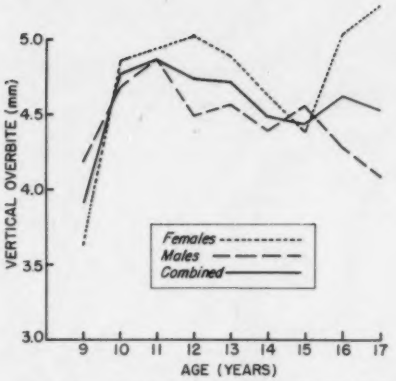
The Vertical Overbite Age 9-17 Years

Age	Mean(mm)	S.D	Range	N
9	3.91	0.736	2.3-4.9	12
10	4.77	0.849	2.4-6.0	25
11	4.87	1.040	2.1-7.0	24
12	4.74	1.023	2.3-6.8	28
13	4.72	0.966	2.4-6.5	24
14	4.48	1.311	1.7-7.4	30
15	4.43	1.040	1.6-6.5	26
16	4.62	1.120	2.3-7.0	20
17	4.52	1.154	2.6-6.7	16

Table 2 illustrates the extent of the vertical overbite for each age, nine through seventeen years. Testing revealed no statistically significant difference betweeen males and females at any of these ages, nor between the Michigan and Iowa samples, therefore the combined data are listed.

From these data it will be seen that the mean overbite for the sample increases in extent from 3.91 mm at age nine years to reach a maximum of 4.87 mm at eleven years. Following this, there is a decrease to 4.43 mm at age fifteen. It is therefore possible to demonstrate, by means of a cephalometric analysis, the same pattern of variation in the vertical overbite which had previously been demonstrated on casts.

In the data presented in Table 2, certain discrepancies are seen when compared with Table 1 (the cast study data). The age at which the peak of the overbite occurs is eleven rather than twelve. There is an apparent rise in the overbite between fifteen and sixteen years and then a reduction at seventeen years. These fluctuations are probably due to the small sample size and the wide range of the individual overbite measurements. It is interesting to note that when the serial data only is considered, the peak of the overbite is at twelve years of age.



Variation in the vertical overbite (Cephalometric Study)

Fig. 4

Figure 4 is a graphic presentation of the data in Table 2. It can be seen that, although the difference between the mean overbite of males and females is not statistically significant, the mean values for females tend to appear slightly greater than those for males except at age nine years. This is agreement with the findings of the cast study. The greatest incremental increase (0.86 mm) for the combined sample occurs between the ages of nine and ten years, and the greatest decrease (0.24 mm) between the ages of thirteen and fourteen. This also is in agreement with the findings of the cast study.

B. *The association of certain craniofacial dimensions with overbite.*

In order to determine which, if any, of the measurements described in the section on method and material were possibly associated with the degree of overbite, correlation coefficients were calculated for each measurement with the degree of overbite. These data are presented in Table 3.

It was found that for each sex there are five of these measurements whose means show statistically significant cor-

Table III
Correlation of Certain Craniofacial Dimensions with Overbite

	Craniofacial Dimension	r	P
M	$\overline{1}$ to ANS - PNS plane	—.237	.02
A	Ramus length	—.372	.01
L	Posterior alveolar height (upper)	—.218	.02
E	Posterior alveolar height (lower)	—.238	.02
S	Mandibular length (C-Gn)	—.239	.02
F			
E	$\overline{1}$ to ANS - PNS plane	—.241	.02
M	Ramus length	—.241	.02
A	$\underline{1}$ to ANS - PNS plane	+.253	.02
L	Anterior alveolar height (lower)	+.429	.01
E	Angle $\overline{1}$ to Go-Gn	—.531	.01
S			
C	$\overline{1}$ to ANS - PNS plane	—.279	.01
O	Ramus length	—.239	.02
M	Anterior alveolar height (lower)	+.208	.05
B	Angle $\overline{1}$ to Go-Gn	—.200	.05

relation with the degree of overbite. Two of these measurements (ramus length, and the distance from the tip of the lower incisor to the ANS - PNS plane) are significant in both sexes, while three measurements are significant only within the one sex.

When the sample was combined without regard to sex, only four measurements show statistically significant correlations with the overbite.

Discussion

This study substantiates the work of Bauerle[13] in showing that there is a variation in the extent of the vertical overbite with age and that, typically, this variation can be represented by a curve with its peak at twelve years of age. The finding of a reduction in the extent of the overbite following twelve years of age is also in agreement with the reduction between twelve and twenty reported by Bjork.[16 17] Since, normally, the teeth of females erupt at an earlier age than do the same teeth in males, it is difficult to explain the finding in the cephalometric study that the overbite is deeper in boys than in girls at age nine years. This peculiarity is probably the result of the relatively smaller sample at this age.

Certain craniofacial dimensions have been shown to hold a statistically significant relationship to the degree of vertical overbite:

1. The anterior alveolar height (upper), which is a measure of the distance from the tip of the maxillary central incisor to the palatal plane (ANS-PNS), was found to hold a significant positive ($p<.02$) correlation with the degree of overbite in females only. When the samples were combined, the relationship no longer was significant.

2. The distance from the tip of the lower central incisor to the palatal plane was found to hold a significant negative relationship to the degree of overbite. This would seem to be an obvious finding in view of the method used in determining the degree of overbite. This

relationship is significant ($P<.02$) in both males and females and in the combined sample ($P>.01$).

3. The anterior alveolar height (lower) was found to have a highly significant positive ($P<.01$) relationship to the degree of overbite in females only. When the two sexes were combined, this relationship was reduced greatly in significance ($P<.05$). This dimension also holds highly significant positive relationships with the anterior alveolar height (upper), and the posterior alveolar height (upper and lower).

4. The length of the ramus of the mandible was found to hold a significant negative relationship to the degree of overbite in both males and females, with the relationship being stronger in males ($P<.01$) than in females ($P=.01$). When the sample was combined, this factor was still significant ($P<.02$). This is in contrast to the findings of Popovich[8] who failed to find any significant relationship between ramus length and the degree of overbite in his Class I groups, but who found such a relationship to exist in his Class II group. This finding would tend to support the work of Diamond[9] who indicated that retardation in ramus length growth was associated with the formation of deep overbite.

5. Posterior alveolar heights (both upper and lower) were found to hold significant negative relationships ($P=.02$) to the degree of overbite in males only. When the male and female samples were combined, these relationships no longer reached a significant level. This finding would tend, with regard to the male sample, to support the findings of Prakash and Margolis[11] who showed that the overbite was related to the lack of upper and lower molar height. The obvious differences in findings between this study and that of Popovich[8], with respect to this dimension, may possibly be due to the fact that in Popovich's data, males and females were combined. In this study, they were treated separately as well, with the result that certain sex differences became apparent.

6. Mandibular length (C-Gn) was found to hold a significant negative relationship to the degree of overbite in males only ($P<.02$). This relationship was not significant when the samples were combined.

7. The angle of the lower incisor to the mandibular plane (Go-Gn) was found to hold a highly significant negative relationship ($P<.01$) to the overbite in the female sample only. When the two samples were combined this relationship, although still negative, was reduced in significance. ($P<.05$).

The greatest reduction in the degree of the vertical overbite comes between thirteen and fifteen years of age. On examining the data for the various craniofacial dimensions, it was found that this was also the period of greatest incremental growth in the ramus of the mandible, also that this increment of growth is much more marked in males than in females. In this respect, the findings are in agreement with those reported by Nanda.[19] If the reduction in overbite after twelve years of age were due to the growth "spurt" in the length of the ramus, one might expect to find greater reduction in overbite in males than in females since the incremental growth in ramus length in males is much greater (males 6.76 mm or 12.4%, females 3.87 mm or 7.6% between thirteen and fifteen years). Using the figures of the cast study since the sample is larger, it was found that this was not the case — the reduction was 0.67 mm in females and 0.52 mm in males. When calculated as a percentage of the greatest overbite (age twelve years), this reduction in females

is 14.8% and in males 12.4%.

By graphing the movement of the tips of the upper and lower incisors in relation to the palatal plane, it was found that the lower incisor between the ages of thirteen and fifteen "grows away" from the palatal plane at a more rapid rate than does the upper incisor. This is another indication that the reduction in overbite after twelve years of age is at least partly due to a rate of growth which is greater in the mandible. Since during this period the mandibular growth rate is greater in males than in females, one would expect to find that the distance between the lower incisor and the platal plane increases proportionately more rapidly in males than in females. The data on this dimension shows this to be true since in the males the increase is 2.46 mm (10.4%), while in females it is only 1.41 mm (5.8%).

Pursuing this line of thought still further, if the distance from the lower central incisor to the palatal plane increases to a proportionately greater degree in males than in females, the degree of overbite should decrease to a greater extent in males than in females. It has already been shown that this is not the case. Examination of the data revealed that the distance between the upper incisor and the palatal plane also was increasing proportionately more rapidly in males than in females. Increase in this dimension in males between thirteen and fifteen years was 1.44 mm (4.7%), while the increase in females was 0.90 mm (3.1%).

One might therefore postulate that the reduction in the degree of overbite after twelve years of age is brought about by growth in the length of the ramus which carries the mandible away from the remainder of the craniofacial complex. The great difference in the rate of ramus length growth in males as compared with females is prevented from "showing up" in the reduction of the overbite by virtue of a compensatory increase in the eruption of the upper incisor in males.

From a clinical point of view it might therefore be reasoned that efforts to reduce the degree of overbite would be least successful in the period before twelve years of age and most successful after this time, particularly during the period thirteen to fifteen years. In assessing the clinical application of this study, however, it must be kept in mind that the actual amount of increase and decrease in the degree of overbite is extremely small and probably of little clinical significance except for its relation to the general pattern of growth.

Summary

A study of the vertical overbite during the period nine to seventeen years was carried out using orthodontic casts and lateral cephalometric films. It was demonstrated that the mean overbite increases from age nine to twelve years and then decreases to the end of the period of observation. There is no statistically significant difference in the degree of overbite in males and females, although the means for females tend to run slightly higher.

The degree of the vertical overbite was shown to be associated with a number of craniofacial dimensions of which ramus length is possibly the most important.

Conclusions

On the basis of this study, it may be concluded that in subjects with Class I (Angle) molar relations:

1. There is a definite cycle to the degree of the vertical overbite which increases from nine to twelve years of age and thereafter decreases, at least to age seventeen.

2. The overbite is related to a num-

ber of craniofacial dimensions, some of which are of importance in both males and females, while others are of importance only in the case of males or females as the case may be.

3. There is some evidence to indicate that the reduction in the overbite following twelve years of age may be due to growth of the ramus of the mandible.

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Medical College of Virginia

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Unilateral Action With Headcap

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Introduction and Review of Literature

In January, 1953 I read a paper before this society entitled "Construction and Use of Unilateral Headcap with Report of Cases". This created quite a discussion about whether or not there was more force exerted on the side to which the soldered joint was off-set. At this time I showed two cases where this unilateral headcap was used and the models showing the case in Class I molar relationship without the use of intermaxillary elastics.

If the previous paper did nothing else, it stimulated further research in the use and construction of the unilateral headcap for which I am grateful as I am sure that all of us will benefit from this further research.

The following January Dr. Arthur J. Block gave a report before this group entitled "An Analysis of Midline and Offcenter Extraoral force". His method was the recording of relative linear measurements of elastic pull required to counterbalance elastic traction applied to each of three types of extraoral headgear placed on a symmetrical base. This was a very good paper, it gave an analysis of the mechanics involved and the results obtained.

In January, 1955 Dr. Vernon R. Boman read a paper before this component regarding the use of off-center extraoral force; this was done using a mechanical base and elastics to measure the force at the end of the E arch. He found that when you bent one arm of the arch bar laterally you had more force applied on that side. He also had an assembly in which there was a swivel joint in one arm of the arch bar with the other arm bent laterally. He found that the pull on the opposite side was increased more than when only the arm of the arch bar was bent laterally.

In September, 1957 Donald C. Haack and Dr. Sam Weinstein presented a paper before the Central Section of the American Association of Orthodontists, entitled "The Mechanics of Centric and Eccentric Cervical Traction". This paper dealt with the forces applied to the molars in both centric and eccentric assemblies using a cervical strap and was computed according to mathematics and physical mechanics. This is a very comprehensive thesis with the forces measured on a mechanical device. They found that when the arm of the arch bar was longer on one side there was a greater force on that side and the difference depended on the difference in length of the arms. They also showed that when a rigid attachment such as a soldered joint was used, even though offset to one side, there was no difference in the pull if the arms were equal. Models of cases under treatment were also shown.

In the October, 1959 issue of the Angle Orthodontist there is a paper by Dr. E. W. Drenker, entitled "Unilateral Cervical Traction with a Kloehn Extraoral Mechanism". This well-written paper also deals with the physical mechanics and mathematics. By analyzing the forces on the molars, he found that by increasing the length of the arm of the arch bar approximately two inches on the side to be moved distally, and also displacing the arm of

Read before the Midwestern Component, Angle Society, January, 1960.

the arch bar three-fourths inch laterally on that side, you would have total, or almost total unilateral action. This has the disadvantage of simultaneously subjecting the dental arch to lateral force, which is undesirable in many cases.

Since all of the previously mentioned papers were done on mechanical devices based on mathematics and physical mechanics, or a combination of the two, I decided to try to accomplish the same things on a clinical basis.

I still was not convinced that an offset headcap exerted the same force on both molars because of past clinical experience. I had tried both lengthening the arm of the arch bar on the side which was to be moved distally and bending the arm of the arch bar laterally, and I had experienced clinically that it was more efficient than the unilateral headcap that I had reported on in my paper in 1953. However, I could not quite believe that the pull was even on the unilateral headcap I had described, since it worked clinically in a large number of cases.

Method and Material

This paper deals with the clinical aspect of the use of a headcap to obtain unilateral action; all measurements and clinical observations were made on one patient. Most of the work previously reported has been on a theoretical and mathematical nature and to my knowledge no direct clinical measurements have been taken from a patient.

The materials used in this project consisted of a regularly constructed E arch of .045 wire soldered in the center to an arch bar made of .059 wire (Fig. 1). Both the E arch and arch bar were constructed of stainless steel wire. The other E arch and arch bar, also steel and of the same diameters, were soldered off center one-half inch to the left. The elastic force was applied

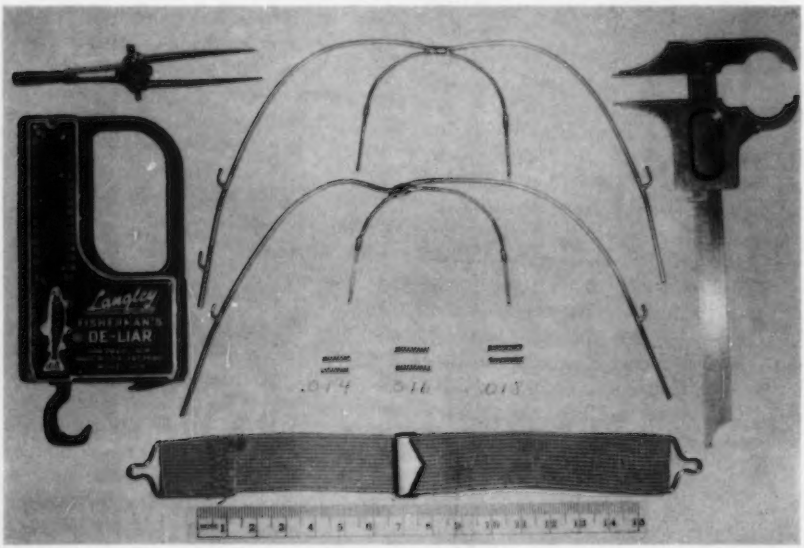

Fig. 1

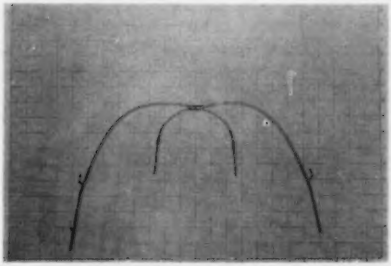

Fig. 2

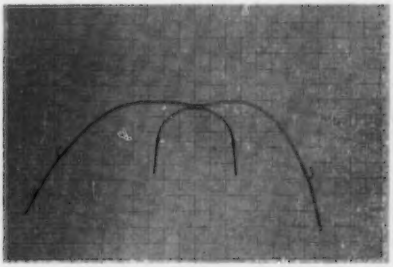

Fig. 3

through the use of an adjustable elastic cervical strap.

Tubes were soldered on the E arches to act as stops twelve mm in front of the molar tubes on both assemblies. The force exerted on the molar tubes was measured by using open coil springs made out of .014 and .016 round stainless steel wire and .018 round yellow Elgiloy wire. The pull on the elastic neck band was accurately measured by using a scale. The compression of the springs was measured in the mouth using a fine pointed divider, then final measurement was made from this by using a Boley gauge.

The sections of the E arches which engaged the molar tubes were reduced in size so that they moved freely through the tubes, thus eliminating as much friction as possible mechanically. These ends were then lubricated to further reduce this friction to the least possible amount.

The same center assembly of E arch and arch bar was used throughout the project, and changes in the length of the arms were accomplished by soldering hooks on the arch bar for attaching the cervical traction band (Fig. 2).

The left arm of the arch bar was also bent laterally so that it was three-fourths inch wider than the right arm, for the recordings in that position (Fig. 3).

The same procedure was followed for the E arch and arch bar assembly that was soldered one-half inch off-center (Fig. 4).

When the project was started with the centered assembly, each set of coil springs was placed on the centered E arch assembly, the neck band applied using one pound pull and measurements were taken of both sides. Then the springs were placed on the opposite side and, using the same pull, measurements were taken again; it was established that the measurements were equal within one-tenth of a millimeter which is within the realm of experimental error.

The neck band was always checked by running the finger between neck band and the neck to be sure it was as free as possible, so that the pull would be equalized with the least possible friction.

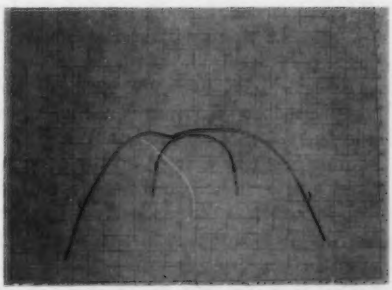

Fig 4

Table I

Pull on Cervical Band	.014 spr. 10 mm		.016 spr. 12 mm		.018 spr. 12 mm	
Symmetrical arch bar	R	L	R	L	R	L
1 lb. Arms even	7.0	7.0	11.0	11.0	11.0	11.0
1" longer on left	6.5	5.8	11.0	10.3	11.1	10.0
2 lbs. Arms even	6.2	6.2	10.1	10.1	11.0	11.0
1" longer on left	6.5	5.8	10.5	9.5	11.5	10.5
2 lbs. Arm ¾" wider on left						
Arms even	7.2	5.5	10.5	9.6	11.0	10.2
1" longer on left	7.1	5.3	10.5	9.5	11.2	10.0
2 lbs. Arch bar ½" off-center			9.5	9.5	10.0	10.0

The same procedure was followed with the E arch and arch bar assembly that was soldered one-half inch off center.

Findings

Using the symmetrically centered assembly and .014 round steel coil spring 10 mm long with the arms of the arch bar even and one pound pull on the cervical band, the springs were compressed to 7.0 mm on the right side and 7.0 mm on the left side (Table I). When the left arm was one inch longer than the right arm of the arch bar, the spring was compressed to 6.5 mm on the right side and 5.8 mm on the left side.

When the amount of pull was increased to two pounds on the cervical band with the arms even, the springs were compressed to 6.2 mm on right side and 6.2 mm on the left side. With the arm of the arch bar on the left side made one inch longer, the springs were compressed to 6.5 mm on the right side and 5.8 mm on the left. When two pounds pull was exerted on the cervical band and the left arm of the arch bar was bent laterally so it was three-fourths inch wider than the right arm with the length of the arms even on the center assembly, the springs were compressed to 7.2 mm on the right side and 5.5 mm on the left side. When the arm of the arch bar on the left side was one inch longer and three-fourths inch wider laterally, the springs were compressed to 7.1 mm on the right side and 5.3 mm on the left side.

Using the symmetrically centered assembly and .016 round steel coil springs 12 mm long with one pound pull on cervical band and the arms of the arch bar even, the springs were compressed to 11.0 mm on the right side and 11.0 mm on the left side. When the pull was one pound and the left arm of the arch bar was one inch longer than the right arm, the springs were compressed to 11.0 mm on the right side and 10.3 mm on left side.

With the arms of the arch bar even and the pull increased to two pounds on the cervical band, the springs were compressed to 10.1 mm on the right side and 10.1 mm on the left side. When the pull was two pounds and the left arm of the arch bar was one inch longer than the right arm, the springs were compressed to 10.5 mm on the right side and 9.5 mm on the left side.

When the pull was two pounds and the left arm of the arch bar was bent laterally so that it was three-fourths inch wider than the right arm and the arms were even, the springs were compressed to 10.5 mm on the right side

and 9.6 mm on the left side. If the left arm of the arch bar was constructed one inch longer and three-fourths inch wider than the right arm and a two pounds pull, the springs were compressed to 10.5 mm on the right side and 9.5 mm on the left.

With a pull of two pounds on the cervical band and the E arch and arch bar assembly soldered one-half inch off-center to the left and using .016 round coil springs, the springs were compressed to 9.5 mm on the right side and 9.5 mm on the left.

When using the symmetrically centered assembly and .018 yellow Elgiloy coil springs 12 mm long with one pound pull on the cervical band with the arms of the arch bar even, the springs were compressed to 11.0 mm on the right side and 11.0 mm on the left side.

If the pull was one pound and the left arm of the arch bar was one inch longer than the right arm, the springs were compressed to 11.1 mm on the right side and 10 mm on the left side.

By increasing the pull to two pounds on the cervical band with the arms of the arch bar even, the springs were compressed to 11.0 mm on the right side and 11.0 mm on the left side. With a pull of two pounds and the left arm of the arch bar one inch longer than the right arm, the springs were compressed to 11.5 mm on the right and 10.5 mm on the left.

When the pull on the cervical band was two pounds and the left arm of the arch bar bent laterally three-fourths inch wider than the right arm, with the arms of the arch bar even, the springs were compressed to 11.0 mm on the right side and 10.2 mm on the left. With a pull of two pounds and the left arm of the arch bar one inch longer and three-fourths inch wider than the right arm, the springs were compressed to 11.2 mm on the right side and 10.0 mm on the left side.

When the pull was two pounds on the cervical band and the E arch and arch bar assembly soldered one-half inch off-center to the left and, using the .018 round Elgiloy coil springs, the springs were compressed to 10.0 mm on the right side and 10.0 mm on the left.

Discussion

It will be noticed from the preceding findings the compression of the springs was equal on both sides when the arms of the arch bar were even when all three size springs were used.

If the arm of the arch bar on the left was one inch longer, the compression of the spring on the right side was equal or less, than when the arms were even, except in cases of the .014 coil spring at the one pound pressure and when the arm of the arch bar was one inch longer and three-fourths inch wider with one pound pressure. In all cases, with all three springs the compression was greater on the left side when the left arm of the arch bar was one inch longer.

The compression of the springs was greater on the left when the arm of the arch bar was three-fourths inch wider, both when the arms were even and when the arm on the left was one inch longer and also three-fourths inch wider.

It would appear from the findings that possibly the .014 steel coil springs were not of sufficient strength to give as accurate a recording as were the .016 steel springs and the .018 yellow Elgiloy springs.

It was noticed that all the springs had a tendency to remain slightly compressed after continued use since the same coil springs of each size were used throughout all the measurements.

This is noticeable particularly on the measurement of the one-half inch off-center assembly with a cervical pull

of two pounds, as this was the last measurement taken and it will be noticed that the measurements are even on both sides, but that it is less than when the two pounds pressure was placed on the centered assembly with the arms even. This slight change in length of the coil springs after continued use can probably be attributed to the fact that they were made from regularly stocked wires, were not tempered and also to the fact that all open coil springs tend to shorten slightly in length after continued usage.

It was also evident when evaluating the forces exerted when the left arm of the arch bar was bent laterally three-fourths inch wider than the right arm that, after use, when the assembly was checked, the left arm did not remain three-fourths inch wider than the right arm.

For the above reason I am of the opinion that the size of the wire for the arch bar should be increased from .059 to .070 or .075 inches as suggested by Haack and Weinstein, especially if you plan to move one arm laterally to increase the width, thereby increasing the force on that side.

Summary

1. The results of these clinical measurements made on a patient with different types of unilateral E arch and arch bar assemblies used showed that you can get definite unilateral action by increasing the length of the arm of the arch bar on the side where you want to move the molar distally.
2. You can also increase the force by bending the arm of the arch bar laterally on the side where you wish to have more distal movement.
3. By lengthening the arm of the arch bar and bending it laterally it is possible to increase the force on the side where you desire more movement. The force will be greater than when either one is used alone.
4. When the E arch and the arch bar are rigidly soldered one-half inch off center and the arms of the arch bar are even, the force is equal on both sides. The probable reason for this appliance working as a unilateral headcap, as I reported in a previous paper, was that the arm on the side to which the joint was offset, was probably wider from the midsagittal plane. I found in forming the off-center assembly that it was difficult to get it symmetrical.
5. No attempt was made to measure the definite amount of force exerted on the molars by the compression of the coil springs or the biological response of the tissues to these forces.

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The Decimal Calendar

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In orthodontics it is frequently necessary to calculate age, duration of treatment and similar intervals of time. The method to be described here is offered as a substitute for conventional methods on the basis of simplicity, accuracy and applicability. It is especially valuable where this type of information is to be handled by auxiliary personnel or subjected to statistical analysis.

Orthodontic intervals are usually measured by a combination of years, months and days. When these different units are combined, their irregular mathematical relationships introduce numerous problems and errors.

The proposed method uses only one unit of time, the *year*. Smaller intervals, down to a single day, are represented by decimal parts of a year. This provides all of the usual advantages of the decimal system in ease and accuracy of calculation. Dates and intervals of time are recorded in less space, and they can be readily manipulated in pencil calculations as well as by mass data handling techniques.

It is possible to convert dates to decimal values, calculate an interval such as age and reconvert the result to conventional units with an improvement in both speed and reliability over the usual method. For most applications, the decimal values can be used directly, so that the final step (reconversion to years, months, and days) can be omitted. Further gains in time and reliability are possible through the use of an adding machine.

Conversion to decimal values and reconversion to conventional units is accomplished with the decimal calendar (Fig. 1). This is in the form of a table arranged so that any date can be located rapidly. Following each date is a three digit decimal figure which represents the actual fraction of a year which has elapsed up to the beginning of that day (midnight).

Values in the table have been calculated to the nearest thousandth, based on a year of 365 days. One thousandth of 365 days is actually 8 hours, 45 minutes, and 36 seconds, so that a single day is slightly less than .003 year. For this reason, the interval between days in the table varies periodically from .003 to .002. For other applications, a table calculated for additional decimal places might be desirable, but this is not necessary for orthodontic purposes. For the same reason, no attempt has been made to compensate for leap years since this would ultimately require the use of an astronomical calendar and special tables for each year.

Determining the Decimal Value for a Date

Dates are represented by the year, followed by the three digit decimal value from the table. Since current dates all begin with 19, this can be omitted from the written date.

Example: 60.987 is the decimal date for Christmas, 1960.

Determining Age or Elapsed Time

Age, or any other interval between dates, is determined from decimal dates by simple subtraction. The value for the earlier date (small figure) is subtracted from that for the later date (larger figure).

The Decimal Calendar

Showing elapsed part of a 365 day year at the beginning of each day

JAN	FEB	MAR	APR	MAY	JUN		JUL	AUG	SEP	OCT	NOV	DEC
1 .000	1 .085	1 .162	1 .247	1 .329	1 .414	.07671 year	1 .496	1 .581	1 .666	1 .748	1 .833	1 .915
2 .003	2 .088	2 .164	2 .249	2 .332	2 .416	.08219 year	2 .499	2 .584	2 .668	2 .751	2 .836	2 .918
3 .005	3 .090	3 .167	3 .252	3 .334	3 .419	.08493 year	3 .501	3 .586	3 .671	3 .753	3 .838	3 .921
4 .008	4 .093	4 .170	4 .255	4 .337	4 .422	.08333 year	4 .504	4 .589	4 .674	4 .756	4 .841	4 .923
5 .011	5 .096	5 .173	5 .258	5 .340	5 .425		5 .507	5 .592	5 .677	5 .759	5 .844	5 .926
6 .014	6 .099	6 .175	6 .260	6 .342	6 .427	= = = =	6 .510	6 .595	6 .679	6 .762	6 .847	6 .929
7 .016	7 .101	7 .178	7 .263	7 .345	7 .430		7 .512	7 .597	7 .682	7 .764	7 .849	7 .932
8 .019	8 .104	8 .181	8 .266	8 .348	8 .433		8 .515	8 .600	8 .685	8 .767	8 .852	8 .934
9 .022	9 .107	9 .184	9 .268	9 .351	9 .436	28 days	9 .518	9 .603	9 .688	9 .770	9 .855	9 .937
10 .025	10 .110	10 .186	10 .271	10 .353	10 .438	30 days	10 .521	10 .605	10 .690	10 .773	10 .858	10 .940
11 .027	11 .112	11 .189	11 .274	11 .356	11 .441	31 days	11 .523	11 .608	11 .693	11 .775	11 .860	11 .942
12 .030	12 .115	12 .192	12 .277	12 .359	12 .444	1/12 year	12 .526	12 .611	12 .696	12 .778	12 .863	12 .945
13 .033	13 .118	13 .195	13 .279	13 .362	13 .447		13 .529	13 .614	13 .699	13 .781	13 .866	13 .948
14 .036	14 .121	14 .197	14 .282	14 .364	14 .449	One month	14 .532	14 .616	14 .701	14 .784	14 .868	14 .951
15 .038	15 .123	15 .200	15 .285	15 .367	15 .452		15 .534	15 .619	15 .704	15 .786	15 .871	15 .953
16 .041	16 .126	16 .203	16 .288	16 .370	16 .455		16 .537	16 .622	16 .707	16 .789	16 .874	16 .956
17 .044	17 .129	17 .205	17 .290	17 .373	17 .458		17 .540	17 .625	17 .710	17 .792	17 .877	17 .959
18 .047	18 .132	18 .208	18 .293	18 .375	18 .460		18 .542	18 .627	18 .712	18 .795	18 .879	18 .962
19 .049	19 .134	19 .211	19 .296	19 .378	19 .463		19 .545	19 .630	19 .715	19 .797	19 .882	19 .964
20 .052	20 .137	20 .214	20 .299	20 .381	20 .466		20 .548	20 .633	20 .718	20 .800	20 .885	20 .967
21 .055	21 .140	21 .216	21 .301	21 .384	21 .468		21 .551	21 .636	21 .721	21 .803	21 .888	21 .970
22 .058	22 .142	22 .219	22 .304	22 .386	22 .471		22 .553	22 .638	22 .723	22 .805	22 .890	22 .973
23 .060	23 .145	23 .222	23 .307	23 .389	23 .474		23 .556	23 .641	23 .726	23 .808	23 .893	23 .975
24 .063	24 .148	24 .225	24 .310	24 .392	24 .477		24 .559	24 .644	24 .729	24 .811	24 .896	24 .978
25 .066	25 .151	25 .227	25 .312	25 .395	25 .479		25 .562	25 .647	25 .732	25 .814	25 .899	25 .981
26 .068	26 .153	26 .230	26 .315	26 .397	26 .482		26 .564	26 .649	26 .734	26 .816	26 .901	26 .984
27 .071	27 .156	27 .233	27 .318	27 .400	27 .485		27 .567	27 .652	27 .737	27 .819	27 .904	27 .986
28 .074	28 .159	28 .236	28 .321	28 .403	28 .488		28 .570	28 .655	28 .740	28 .822	28 .907	28 .989
29 .077		29 .238	29 .323	29 .405	29 .490		29 .573	29 .658	29 .742	29 .825	29 .910	29 .992
30 .079		30 .241	30 .326	30 .408	30 .493		30 .575	30 .660	30 .745	30 .827	30 .912	30 .995
31 .082		31 .244		31 .411			31 .578	31 .663		31 .830		31 .997
$\frac{1}{12}$ year	$\frac{2}{12}$ year	$\frac{3}{12}$ year	$\frac{4}{12}$ year	$\frac{5}{12}$ year	$\frac{6}{12}$ year	Dr. Raymond E. Thurow	$\frac{7}{12}$ year	$\frac{8}{12}$ year	$\frac{9}{12}$ year	$\frac{10}{12}$ year	$\frac{11}{12}$ year	$\frac{12}{12}$ year
.083	.167	.250	.333	.417	.500		.583	.667	.750	.833	.917	1.000

One day = .00274 year
One week = .01918 year

Fig. 1

Example:

Date of examination =
Jan. 27, 1961=61.071
Date of birth =
Apr. 15, 1944 = 44.285
Age at examination=16.786 years

Reconversion to Years, Months, and Days

Two methods are available for reconverting decimal values to conventional units depending on the degree of accuracy desired. The short method provides accuracy comparable to that obtained when all calculations have been made in conventional units, and is adequate for most purposes. The 'standardizing' method uses standardized months each 1/12 year in length. This provides more consistent accuracy by eliminating the errors introduced by calendar months of different length.

In either method of reconversion, the decimal value being converted may sometimes fall between two figures in the table. In this situation, the *next lower* figure (*not* the nearest figure) represents the correct date. This is because each figure in the table represents the *beginning* of the day.

Reconversion by the Short Method

Locate the date in the table which corresponds to the decimal value being converted (for intermediate figures, take the next lower date as explained above). Use the number of months and days represented by the date shown.

Example: Convert age 16.786 years into months and days.

October 15 is the date corresponding to .786.

October 15 is 9 months and 15 days after the first of the year.

Therefore, 16.786 years = 16 years, 9 months, 15 days.

Reconversion by the Standardizing Method

Standardized monthly intervals of 1/12 year are shown at the bottom of the calendar table. The largest of these values which is included in the value being converted indicates the number of whole standardized months included in that figure. Subtracting this value leaves a remainder which represents the number of days. The table for the month of January is consulted for the highest value included in the remainder, and the number of days read directly.

Example: Convert 16.786 years into years, standardized months, and days.

The largest standardized monthly value included in 16.786 is .750 (9/12 year).

Subtracting, .786
-.750
———
.036

Consulting the table for January, .036 = 14 days.

Therefore, 16.786 years = 16 years, 9 months, 14 days.

The standardized monthly intervals in the table represent units of a complete twelfth of a year, not the beginning of the last day of the month. These values actually represent the beginning of the first day of the following month, so that a value coinciding with one of these figures will represent a number of months plus one day. On the other hand, a value just below one of the 1/12 year figures will yield a result showing one month less, plus thirty or thirty-one days. This may be changed to show an additional whole month (1/12 year = 30.417 days).

SUMMARY

Dates may be recorded in less space, and ages and similar periods of time may be calculated with greater speed and accuracy through the use of decimal fractions of a year. A calendar-table is presented making conversion to and from these units both rapid and simple.

Additional details which might be required for special purposes or maximum accuracy are also presented.

The Angle Orthodontist

A magazine established by the co-workers of Edward H. Angle, in his memory . . .

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